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RESPONSE TO ACTION ITEMS FROM PUBLIC MEETINGS BETWEEN NRC AND DOE TO DISCUSS RAI FOR THE SAVANNAH RIVER SITE

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Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

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Introduction

On July 27, 2005, and August 17-18, 2005, the staff and management from the U.S. Nuclear Regulatory commission (NRC) and the U.S. Department of Energy (DOE) met to discuss DOE's responses (WSRC 2005) to NRC's Request for Additional Information (RAI) on the *Draft Section 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site* (DOE 2005). As a result of the meetings, DOE is providing additional information in response to twenty two Action Items identified at the July 27, 2005 meeting (NRC 2005a) and eleven Action Items identified at the August 17-18, 2005 meeting (NRC 2005b) responses to the Action Items are attached.

References:

DOE, 2005, *Draft Section 3116 Determination Salt Waste Disposal Savannah River Site*, DOE–WD–2005–001, U. S. Department of Energy.

WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal At The Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC, 2005a, Memorandum from Anna Bradford/RA/ to Scott Flanders, Deputy Director, August 5, 2005, *July 27, 2005 Meeting Summary:Meeting with U.S. Department of Energy to Discuss Responses to Request for Additional Information for the Savannah River Site.*

NRC, 2005b, Memorandum from Anna Bradford/RA/ to Scott Flanders, Deputy Director, September 2, 2005, *August 17-18, 2005 Meeting Summary:Meeting with U.S. Department of Energy to Discuss Responses to Request for Additional Information for the Savannah River Site*

Action Item 1 (7/27/05): ***Cited Reference for Reboul 2005***

Provide reference cited in RAI responses titled "Removal of Highly Radioactive Nuclides from SRS Salt Waste," Reboul 2005.

SRS Response: The responses provided in *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site* (WSRC 2005a) for RAI Comments 1, 11, and 12 cite Reboul 2005 as a reference document. The proper reference document for these RAI responses is *Radionuclides in SRS Salt Waste* (WSRC 2005b). This reference document replaces Reboul 2005 in all instances. This document was provided to the U. S. Nuclear Regulatory Commission electronically on August 9, 2005 (DOE 2005).

References:

DOE, 2005, *Technical Reference Supporting Salt RAI Response #11*, electronic mail message, Randall Kaltreider to Anna Bradford et al., August 9, 2005.

WSRC, 2005a, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2005b, *Radionuclides in SRS Salt Waste*, CBU-PIT-2005-00195, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 2 (7/27/05): ***Data to Provide Model Support for Simulation Results***

Provide data that could provide model support for simulation results (RAI 3).

SRS Response: The information provided in the Savannah River Site (SRS) response to the U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) Comment 3 (WSRC 2005) encompasses all currently available field data providing model support for simulation results. This showed good validation of the PORFLOW model with tritium monitoring data. In addition, the response to NRC RAI 17 (WSRC 2005) showed how the PORFLOW code has been validated by others.

References:

WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 3 (7/27/05): ***Support for DOE Definition of Highly Radioactive Radionuclides***

Demonstrate that DOE's definition of highly radioactive radionuclides is based on conservative analysis or provide adequate model support (RAI 11).

SRS Response: As a preliminary matter**,** the following response clarifies and summarizes DOE's approach for identifying highly radioactive radionuclides for the purposes of 3116(a)(2) of the Ronald W. Reagan Defense Authorization Act for Fiscal Year 2005 (NDAA), and identifies those radionuclides in the Savannah River Site (SRS) low-activity salt waste that DOE views as being highly radioactive radionuclides.[1] The response then addresses the specific issue posed by Action Item 3 and addresses other related oral questions asked by the NRC.

<u>Approach and Identification of Highly Radioactive Radionuclides in the SRS Salt Waste for the purposes of 3116(a) (2) of the NDAA</u>

Based on consultation with the NRC, DOE views "highly radioactive radionuclides" to be those radionuclides that, using a risk-informed approach, contribute most significantly to radiological risk to workers, the public, and the environment. Cesium-137 (including its daughter, Ba-137m), Sr-90 (including its daughter Y-90), four alpha-emitting transuranic (TRU) nuclides (Pu-238, Am-241, Cm-244 and Pu-239), Se-79, Tc-99 and I-129 are the highly radioactive radionuclides in the SRS low-activity salt waste for disposal that DOE believes, on the basis of a risk-informed approach, may contribute significantly to radiological risk to workers, the public and the environment, taking into account scientific and health physics principles, knowledge and expertise.[2] This list of highly radioactive radionuclides was developed beginning with the inventory of radionuclides in the SRS salt waste.[3] DOE reviewed this inventory of radionuclides and identified those radionuclides in Tables 1 and 2 of 10 CFR 61.55[4], as well as any additional radionuclides that may be important to meeting

[1] DOE is providing this summary of its approach to clarify any confusion or misinterpretation of DOE's Response to RAI 11, particularly with respect to Se-79, Tc-99 and I-129. As discussed later in this response to Action Item 3, DOE views Se-79, Tc-99 and I-129 in the SRS salt waste to be highly radioactive radionuclides for the purposes of 3116(a) of the NDAA.

[2] Some of the radionuclides listed as highly radioactive radionuclides for the SRS low-activity salt waste may not be listed for other 3116 Determinations if such radionuclides are not present in the waste or do not contribute to dose to the workers, the public, or the intruder.

[3] As discussed in footnote 10 of DOE's Draft 3116 Determination (DOE 2005), DOE has reviewed the inventory of radionuclides in the salt waste in the SRS waste tanks, as reflected in the current Waste Characterization System database.

[4] Although Tables 1 and 2 in 10 CFR 61.55 specify concentration limits for certain radionuclides in the form of activated metal, DOE includes such radionuclides, if present in the waste, in the list of "highly radioactive radionuclides" as it exists in the waste, without regard to whether such radionuclides are in the form of activated metal. Consistent with Table 1, DOE excludes alpha-emitting transuranic nuclides with half lives of 5 years or less from the list of highly radioactive radionuclides. As discussed in footnote 10 of DOE's Draft 3116 Determination (DOE 2005), all radionuclides in Tables 1 and 2 were considered with respect to section 6 of the draft Determination (concerning

the performance objectives in 10 CFR 61, Subpart C because they contribute to the dose to workers, the public, and/or the inadvertent intruder (for one or more reasonable intruder scenarios) in the expected and degraded cases. In DOE's view, this approach results in a risk-informed list of highly radioactive radionuclides that includes: those short-lived radionuclides that may present risk because they produce radiation emissions that, without shielding or controls, may harm humans simply by proximity to humans without inhalation or ingestion; and those long-lived radionuclides that persist well into the future, may be mobile in the environment, or may pose a risk to humans if inhaled or ingested.

The above list of highly radioactive radionuclides is the same as the list of radionuclides considered in DOE's Draft 3116 Determination (DOE 2005) with the exception of Sn and U isotopes. Tin and uranium isotopes are excluded from the list of highly radioactive radionuclides based on the results of the 2005 SA (Cook et al. 2005), which used improved analytical models and additional sensitivity analyses that more accurately depicted the potential dose impacts of salt waste disposal.[5]

Action Item 3 Issues

Of the highly radioactive radionuclides listed above, Sr-90, Cs-137 and four alpha-emitting transuranic (TRU) nuclides (Pu-238, Am-241, Cm-244 and Pu-239) are the radionuclides for salt waste disposal at Savannah River Site that contribute most significantly to radiological risk to the workers, the public and the environment, as discussed in the Savannah River Site (SRS) response to the U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) Comment 11 (WSRC 2005a). For the reasons discussed below, DOE believes that the analysis outlined in the response to NRC RAI Comment 11, its

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3116(a)(3)(A) of the NDAA) and, where relevant, section 7 of the draft Determination (concerning 3116(a)(3)(A)(i) of the NDAA). However, radionuclides with half lives of 5 years or less, as well as H-3, C-14, Co-60 and Ni-63 (which are present in low concentrations that are well below Class A concentration limits), were not discussed in section 5 of the draft Determination concerning "removal to the extent practical." DOE notes that this approach has not been questioned by the NRC or in public comments.

[5] Subsequent to the development of the Draft Section 3116 Determination (DOE 2005), DOE prepared an updated Special Analysis (SA) (Cook et al. 2005) for the Saltstone Facility using improved analytical models and additional sensitivity analyses that more accurately depicted the potential dose impacts of salt waste disposal. Based on the results of this SA and subsequent analysis outlined in the response to NRC RAI Comment 11, Sn-126 and the uranium isotopes were found to be insignificant contributors to the future potential risk to the public, workers, or the environment and, therefore, are no longer being considered for inclusion in the list of highly radioactive radionuclides.

In DOE's response to RAI 11, DOE showed that the concentrations of Se-79, Tc-99 and I-129 in the SRS salt waste are such that they have low associated risks in the expected case based on DOE's analysis premised on the updated SA. DOE also noted that it would not be useful, sensible or reasonable -- that is, it would not be "practical" -- to further remove those radionuclides from the SRS salt waste. DOE also noted that, based on the results of a risk-informed screening approach recommended by the NRC, Se-79, Tc-99 and I-129 would not necessarily be highly radioactive radionuclides in the expected case. However, DOE continues to include Se-79, Tc-99 and I-129 as "highly radioactive radionuclides" as it did in DOE's Draft 3116 Determination (DOE 2005) based on further NRC consultation.

supporting documentation, and DOE's sensitivity analyses provides a conservative approach which shows that Sr-90, Cs-137, Pu-238, Pu-239, Am-241 and Cm-244 contribute more significantly to radiological risk than the other "highly radioactive radionuclides" in the SRS salt waste.

Approach Includes Conservative Assumptions

The analysis supporting RAI Comment 11 (see response to NRC RAI Comment 11) was based on a series of assumptions/inputs pertaining to waste characterization, disposition, and environmental transport, which were clearly conservative as compared to the anticipated Saltstone Disposal Facility system behavior, and, as explained below, would generate model results which were more pessimistic in several respects than the anticipated Saltstone Disposal Facility system behavior. A summary of the key assumptions/inputs making this analysis conservative is given below:

- Untreated radionuclide inventories represent upper bounding values
  - Characterization approach is conservative for soluble and insoluble phases
  - Characterization assumes all dissolved salt contains 600 mg suspended sludge solids per liter
  - Characterization assumes none of suspended solids are removed via settling
  - Characterization assumes all solids within the saltcake matrix are sent to the SDF

- For the all-pathways scenario, distribution coefficients (K_d) for the baseline case are lower bounding values (where actual K_ds were not available) resulting in higher contaminant releases
  - Environmental characterization of surrounding soil material indicates that it is predominately sandy loam (Cook et al. 2005)
  - The soil K_ds are for sand (lower K_d), rather than sandy loam (higher K_d)

- For the all-pathways scenario, estimated doses are based on "peak" groundwater concentrations for radionuclides whose peak concentrations are not coincident in time -- thus summing the peak doses is conservative.

- For the all-pathways scenario, peak groundwater contribution and peak air contribution are summed, despite differences in times when groundwater and air concentrations are maximum – thus summing these two is conservative.

- For the worker scenario, photon doses are based on liquid waste, not solidified waste. This is conservative because addition of grout reduces radionuclide concentrations and increases photon shielding.

Implications of All-pathways Dose Sensitivity Analysis

As discussed in the response to NRC Action Item 10 (8/17/05), a series of over 30 sensitivity cases was performed with the model used to estimate the all-pathways public dose rates to determine how sensitive the projected doses are to the selection of key input parameters. This model served as the basis for computing the “baseline” Vault 4 inventory limits in the 2005 Vault 4 Special Analysis (Cook et al. 2005). Key input parameters for the model were changed to more pessimistic values, many of which were set to values considered beyond credible. The purpose of this important exercise was to first identify the critical input parameters to the model and then to gain an understanding of how much each parameter can vary before the resulting projected doses will exceed associated performance objectives.

It is important that the models provide a realistic representation of the physical and chemical processes that will occur within the saltstone disposal vaults and surrounding environment for the next 10,000 years. An analysis of the results of the sensitivity cases indicated that the public dose estimates were most sensitive to the two following parameters: 1) amount of precipitation, which affects the infiltration rate of the water reaching the disposal system; and 2) the reduction/oxidization conditions of the saltstone disposal vault and the saltstone grout, which specifically determine the distribution coefficient of technetium (See response to NRC Action Item 10 (8/17/05)). These parameters are ones that DOE has a high degree of confidence will perform as described in the baseline case. This is based on the availability of historic weather data, ability to design and construct a vault cover system that will perform as modeled, and use of the slag as a key construction material in both the vault and saltstone waste form. The unique inclusion of slag in both the vault and the saltstone waste form will maintain a reducing environment as modeled and therefore significantly slow down the release of the technetium to the environment (See response to Action Item 10 (8/17/05)).

With this understanding of the model’s sensitivities and the engineering controls that have been included or will be designed (such as inclusion of slag as an inherent construction material in both the vault and the saltstone waste form and the design of the closure cap respectively, see NUREG 1623, “Design of Erosion Protection for Long-Term Stabilization,” September 2002) and the associated conservatism in the radionuclide inventory that will be sent to the SDF, DOE believes that the baseline case can be used for the purposes of identifying those radionuclides that, if left untreated and solidified, would contribute most significantly to the radiological risk to the workers, the public and the environment.

Effect of Overlapping Plumes in All-pathways Scenario

The effect of overlapping groundwater plumes resulting from the presence of multiple vaults in the SDF will be a dose increase of ~25% for two adjacent vaults (Cook et al. 2005) and approximately a factor of two for the entire SDF (WSRC 2005c). In this regard, DOE notes that the all-pathways dose rate of the baseline case is extremely low (two orders of magnitude below the limit – see Table 3 of WSRC, 2005b).

Confirmation of Highly Radioactive Radionuclides

Based on consultation with the NRC, DOE views Cs-137 (including its daughter Ba-137m), Sr-90 (including its daughter Y-90), four alpha-emitting transuranic (TRU) nuclides (Pu-238, Am-241, Cm-244 and Pu-239), Se-79, Tc-99 and I-129 to be the highly radioactive radionuclides in the SRS low-activity salt waste that, on the basis of a risk-informed approach, contribute significantly to radiological risk to workers, the public and the environment, taking into account scientific and health physics principles, knowledge and expertise. Of these highly radioactive radionuclides, the response to NRC RAI Comment 11 showed that, in the expected (baseline) case and using a risk-informed analysis recommended by NRC, Sr-90, Cs-137, and four alpha-emitting transuranic (TRU) nuclides (Pu-238, Am-241, Cm-244 and Pu-239) contribute most significantly to radiological risk to the workers, the public and the environment. Subsequent to the issuance of the response to NRC RAI Comment 11 -- and pursuant to consultation with the NRC that reflects a more conservative perspective and for the reasons described in the Draft 3116 Determination -- DOE has retained Se-79, Tc-99 and I-129 on the list of highly radioactive radionuclides for SRS salt waste as in DOE's Draft 3116 Determination (DOE 2005).

Contribution to Radiological Risk Associated with Se-79, Tc-99 and I-129

The anticipated all-pathways dose rate from Se-79 in the 2005 Vault 4 Special Analysis (Cook et al. 2005) is 4.6E-02 mrem/yr. In the sensitivity analysis performed in response to NRC Action Item 10 (8/17/05), the only sensitivity case where the Se-79 dose (61 mrem/yr) exceeded the 25 mrem/yr maximum all-pathways dose rate was in scenario 33, where an infiltration rate of 25 cm/year was assumed through the upper Geosynthetic Clay Liner (GCL) and the drains were assumed to be completely silted up throughout the simulation. This was coupled with a pessimistic value of 5E-7 cm/sec for the hydraulic conductivity of the vault and saltstone grout throughout the simulation and a factor of 10 increase in the effective diffusivity for the vault and saltstone grout. This scenario is not credible in that it represents a disposal system that has no closure cap and no vault and in which the saltstone grout had properties similar to SRS sandy clay soil. See response to NRC Action Item 10 (8/17/05).

The anticipated all-pathways dose rate from Tc-99 in the 2005 Vault 4 Special Analysis (Cook et al. 2005) is extremely small (1.6E-13 mrem/yr). In the sensitivity analysis performed in response to NRC Action Item 10 (8/17/05), the sensitivity cases where the Tc-99 dose (90 mrem/yr for scenario 22; 1,200 mrem/yr for scenario 30; 34,000 mrem/yr for scenario 33 oxidizing; and 31 mrem/yr for scenario 33 reducing) exceeded the 25 mrem/yr maximum all-pathways dose rate were those cases in which the saltstone grout and the concrete vaults were both assumed to have a complete loss of reducing capacity at time zero. This assumption is considered unrealistic given that slag is an integral part of the saltstone grout and vault and its demonstrated effectiveness in reducing Tc-99 (see response to NRC Action Item 9 (7/27/05)). In addition, Scenario 33 is not credible because it represents a hypothetical disposal system that has no closure cap and no vault and in which the saltstone grout had properties similar to SRS sandy clay soil. See response to NRC Action Item 10 (8/17/05).

The anticipated all-pathways dose rate from I-129 in the 2005 Vault 4 Special Analysis (Cook et al. 2005) is 2.6E-03 mrem/yr. In the sensitivity analysis performed in response to NRC Action Item 10 (8/17/05), the only sensitivity cases where the I-129 dose (130 mrem/yr) exceeded the 25 mrem/yr maximum all-pathways dose rate was in scenario 33, where an infiltration rate of 25 cm/year was assumed through the upper Geosynthetic Clay Liner (GCL) and the drains were assumed to be completely silted up throughout the simulation. This was coupled with a pessimistic value of 5E-7 cm/sec for the hydraulic conductivity of the vault and saltstone grout throughout the simulation and a factor of 10 increase in the effective diffusivity for the vault and saltstone grout. As discussed above, this scenario is not credible in that it represents a disposal system that has no closure cap and no vault and in which the saltstone grout had properties similar to SRS sandy clay soil.

For perspective, using the analytical process discussed in the response to NRC RAI Comment 11, even when using the radionuclide inventories in the solidified salt waste assuming no radionuclide removal treatment of the waste stream, the resultant dose rates due to Se-79, Tc-99 and I-129 were 3.3E-01 mrem/yr, 4.5E-13 mrem/yr and 6.3E-03 mrem/yr, respectively (WSRC 2005a). All doses, individually and in combination, were well below the 25 mrem/yr performance objective suggesting that these radionuclides pose a low radiological risk to workers, the public and the environment in the expected or baseline case.

Removal to the Maximum Extent Practical

Removal of Sr-90, Cs-137 and the alpha-emitting transuranic nuclides is discussed in the Draft 3116 Determination (DOE 2005) and in the response to NRC RAI Comment 11 (WSRC 2005a).
With respect to Se-79, Tc-99 and I-129, the concentrations of these radionuclides in the salt waste are such that they do not present a significant risk to the workers, the public or the environment in the expected (baseline) case as discussed above. Because of the low associated risk, these radionuclides are not targeted for removal by the processes DOE plans to deploy. In this regard, the "maximum

extent practical" removal standard in Section 3116 of the NDAA contemplates, among other things, the exercise of expert judgment and consideration of the sensibleness, reasonableness and usefulness of further removal of radionuclides. For the SRS salt waste streams, the associated risks of Se-79, Tc-99 and I-129 are so low that it would not be sensible or reasonable to target these radionuclides for further removal. Nevertheless, because of the processes utilized at SRS, removal of the insoluble fraction of Se-79, Tc-99 and I-129 will be accomplished through a combination of settling and cross-flow filtration. The insoluble fraction within the salt waste comprises approximately 60%, 6%, and 0.05% respectively of the SRS inventory for each of these radionuclides (WSRC 2005b). However, removal of the soluble-phase of these radionuclides is impractical due to the low maturity of removal technologies (Peterson 1996), particularly in light of the low contribution to risk posed by these radionuclides in the expected (baseline) case. Because of the relative low risk associated with these radionuclides (WSRC 1992, Cook et al. 2005), DOE has not historically contemplated removal of these radionuclides from waste. No significant research and development activities have been conducted on removal of these radionuclides.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

DOE, 2005, *Draft Section 3116 Determination Salt Waste Disposal Savannah River Site*, DOE–WD–2005–001, U. S. Department of Energy.

Peterson, C. A., 1996, *Technical Basis for Classification of Low-Activity Waste Fraction from Hanford Site Tanks*, WHC-SD-WM-TI-699, Revision 2.

WSRC, 1992, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility,* WSRC-RP-92-1360, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2005a, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2005b, *Radionuclides in SRS Salt Waste*, CBU-PIT-2005-00195, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC 2005c, Statement by Cook, J. R., principal author of "*Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*," WSRC-TR-2005-00074, May 26, 2005, made at the U. S. Nuclear Regulatory Commission Public Meeting held on August 17-18, 2005 in North Augusta, South Carolina.

Action Item 4 (7/27/05): ***Infiltration Rates to the top of the Vaults***

Provide infiltration rates to the top of the vaults and sensitivity analysis evaluating combinations of parameters (RAI 19).

SRS Response: Infiltration rates to the top of the vaults along with the results and evaluation of new sensitivity analysis is provided in the response to U. S. Nuclear Regulatory Commission (NRC) Action Item 10 (8/17/05) contained within this document. Information on infiltration rates can be found in Attachment 1 of the Response to NRC Action Item 10. The sensitivity cases associated with variations in the infiltration rate are sensitivity cases 24, 25, 30, and 33.

In scenario 24, the average precipitation used in the Hydrologic Evaluation of Landfill Performance (HELP) code to calculate infiltration to the PORFLOW model domain was increased by 25% based on a hypothetical climate change. An additional radionuclide, Np-237, was included in the scenario.

In scenario 25, the increased precipitation (scenario 24) was combined with scenarios 5 and 9 in which the degradation rate of saltstone grout and the vault was increased to yield a final saturated hydraulic conductivity of 1E-8 cm/s (i.e., α_{vault} = 2.0 and $\alpha_{Saltstone}$ = 1.5). An additional radionuclide, Np-237, was included in the scenario

In scenario 30, scenarios 25 and 29-oxidized were combined to address the combined effects of oxidized saltstone grout and vault (i.e., no slag present from time equals zero), increased precipitation, and increased degradation of the vault and saltstone grout.

In scenario 33, infiltration to the vault was set at 25 cm/yr throughout the simulation and the closure cap drains are silted to allow increased infiltration to go to the saltstone grout. The hydraulic conductivity of the vault and saltstone grout were set to 5E-7 cm/sec throughout the simulation. Effective diffusivity for the vault and saltstone grout was increased by a factor of 10 (i.e., to 1E-7 cm^2/sec for the vault and 5E-8 cm^2/sec for saltstone grout). The oxidation of saltstone grout was modeled as 0 and 100% (i.e., no slag present from time equals zero).

A detailed discussion of the results from these sensitivity cases is included in the response to NRC Action Item 10 (8/17/05).

Action Item 5 (7/27/05): *Technical Details on Erosion Design*

Provide additional technical details on erosion design (RAIs 22, 25).

SRS Response: Information on the technical details of the Saltstone Disposal Facility (SDF) vault erosion design is provided in the response to U. S. Nuclear Regulatory Commission Action Item 3 (8/17/05) contained within this document.

Action Item 6 (7/27/05): *Root Pentrations on Cap Performance*

Provide root depth for pine trees and possible impacts on cap performance (e.g., fast pathways) (RAI 24)

SRS Response: The potential impacts on closure cap performance due to the depth of pine tree roots are discussed below considering the following:

- Pine tree root structure and decomposition
- Assumed closure cap degradation due to pine forest succession and resulting impact of root penetration on infiltration through the upper geosynthetic clay liner (GCL)
- Root impact on the lower backfill, lower drainage layer, and lower GCL

Pine Tree Root Structure and Decomposition

The root structure of pine trees consists of the root mass immediately below the trunk, the feeder roots, and the structural or tap roots. The root mass, immediately below the trunk, which is essentially the diameter of the trunk at the ground surface, consists of the intertwined mass of feeder and tap roots, is shaped like an inverted cone, and extends two to three feet deep. Feeder roots extend laterally out from the tree, are of a small diameter, and are located primarily in the top 18 inches of the soil. Structural or tap roots penetrate deeper into the soil and are located mainly near the center of the tree spread (i.e., concentrated near the main trunk). A mature pine will typically have five tap roots, of which, four go to a depth of about six feet and one to about 12 feet. Tap roots have a typical diameter of three inches in the top foot of soil and taper with depth to 0.25 inches at its terminus. Hard layers and water-saturated layers will slow root penetration. A continuous water surface will stop elongation. A hard layer will eventually be penetrated.

Very rapid yearly turnover of feeder roots occurs in the soil. Tap roots, however, are maintained over the life of the tree and exhibit little turnover prior to death. They enlarge with yearly growth, similar to branches, although anatomically different and at a slower rate. When a pine tree dies, decomposition of roots near the ground surface should occur fairly quickly due to a better microclimate for microbial populations than at depth. Decomposition of roots at depth will be fairly slow, depending on the soil environment and aeration. It is assumed that it will take 25 years for the decomposition of intermediate-depth roots and 30 years at depth due to the soil environment. After death, some shrinkage of roots may occur prior to decomposition. In general, the only hole produced in the ground due to the death and decomposition of a pine tree is associated with its conical shaped root mass immediately below the trunk. Holes associated with the feeder root and tap root shrinkage and decomposition are not generally observed. These holes in general quickly fill with soil due to hydraulic and/or earth pressure induced soil movement. (Bohm 1979, Burns and Hondala 1990, Ludovici et al. 2002, Taylor 1974, Ulrich et al. 1981, Walkinshaw 1999, and Wilcox 1968)

Assumed Closure Cap Degradation due to Pine Forest Succession and Resulting Impact of Root Penetration on Infiltration through the Upper GCL

The United States Environmental Protection Agency (USEPA 1987), through sensitivity analysis using the Hydrologic Evaluation of Landfill Performance (HELP) model and HELP model comparisons to field data from 20 landfill cells, determined the following:

> "Hydraulic conductivity values for the topsoil, lateral drainage layers, and clay liners are the most important parameters in determining the water budget components. These parameters are particularly important in estimating the percolation through the landfill."

On this basis, Phifer and Nelson 2003 (Sections 5.0 and 6.0 and Appendix P) placed primary focus on degradation of the Saltstone Disposal Facility (SDF) closure cap topsoil, lateral drainage layers, and upper geosynthetic clay layer (GCL). The topsoil was degraded through erosion, the lateral drainage layers were degraded through siltation, and the upper GCL was degraded through pine forest succession and associated tap root penetration. The tap root penetration results in holes through the GCL. This allows the overlying drainage layer to fill the holes after the pine tree dies and the tap roots decompose. In order to be conservative, Phifer and Nelson 2003 (Sections 5.0 and 6.0 and Appendix P) assumed that, upon death of a pine tree, its tap roots through the upper GCL immediately disappeared and that no GCL self-healing occurred. Credit was not taken for the 25 to 30 years required for the tap root to decompose. Rather, it was assumed that an open hole through the GCL was immediately available to transmit water. The holes in the GCL essentially act as direct conduits from the upper drainage layer to the lower backfill layer. When saturated conditions occur in the drainage layer after major precipitation events, cones of depression are created around the holes in the GCL with a radius of influence much greater than the radius of the hole. This means that a small area of GCL holes can greatly reduce the lateral flow of water in the drainage layer and increase the vertical flow into the lower backfill.

Based upon these conservative assumptions, the range of annual infiltration that could result from annual precipitation ranging from approximately 30 to 70 inches/year has been determined for years 0, 300, and 1,800 which were previously modeled (Phifer and Nelson 2003; Section 6.2, Phifer 2003; Section 5.2). At year 0, the closure cap is intact; at year 300, holes have begun to form through the upper GCL; and, at year 1,800 and beyond, the upper GCL has essentially failed hydraulically. Figure 6-1 provides plots of annual infiltration over an annual precipitation range of 30 to 70 inches/year for years 0, 300, and 1,800, and Table 6-1 provides the statistics for the data upon which the Figure 6-1 plots are based along with the percentage of holes through the upper GCL at the given time. Additional information regarding the generation of these ranges of annual infiltration can be found in the response to NRC Action Item 12 (7/27/05).

At year 0, with no holes through the upper GCL, infiltration through the upper GCL ranges from 0.13 to 0.73 with an average of 0.36 inches/year due to 30 to 70 inches of precipitation per year (see Table 6-1). At year 300, with holes in only 0.018 percent of the upper GCL, infiltration through the upper GCL ranges from 0.88 to 6.52 with an average of 3.0 inches/year due to this precipitation range (see Table 6-1). At year 1,800, the upper GCL has essentially failed hydraulically with holes only in 0.29 percent of the upper GCL, resulting in infiltration through the upper GCL ranging from 3.1 to 30.6 with an average of 13.8 inches/year due to this precipitation range (see Table 6-1). As seen, significant increases in annual infiltration through the upper GCL develop rapidly with the presence of very few holes in the upper GCL.

Figure 6-1. Annual Infiltration as a Function of Annual Precipitation

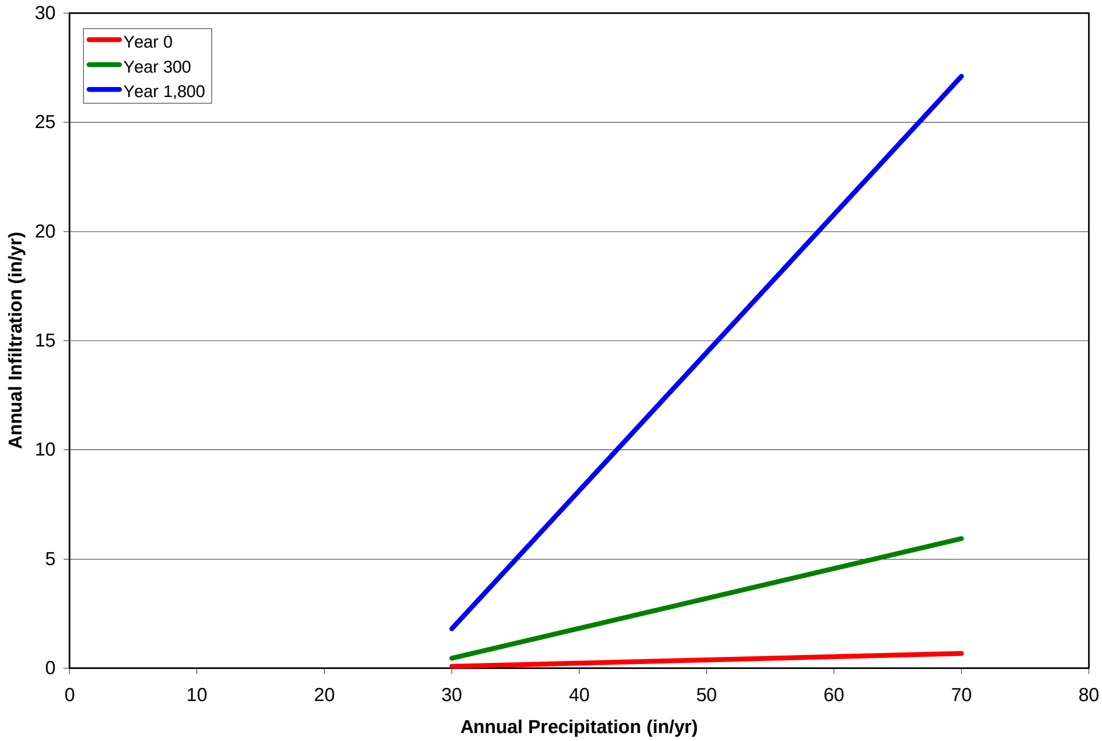

Table 6-1. Annual Precipitation and Annual Infiltration Data Statistics

Parameter	Annual Precipitation (in/yr)	Annual Infiltration at Year 0 (in/yr)	Annual Infiltration at Year 300 (in/yr)	Annual Infiltration at Year 1,800 (in/yr)
Maximum	68.90	0.733	6.516	30.632
Average	48.90	0.362	3.047	13.762
Minimum	29.28	0.131	0.878	3.144
Range	39.62	0.60	5.64	27.49
Standard Deviation	7.73	0.129	1.224	5.553
		Year 0	Year 300	Year 1,800
Percentage of GCL with holes (%)		0	0.018	0.29

Also based upon these conservative assumptions, the range of daily infiltration that could result from daily precipitation ranging from 0 to 6.87 inches/day has been determined for years 0, 300, and 1,800 (Phifer and Nelson 2003; Section 6.2, Phifer 2003; Section 5.2). Figure 6-2 provides plots of daily infiltration over the daily precipitation range of 0 to 6.87 inches/day for years 0, 300, and 1,800, and Table 6-2 provides the statistics for the data upon which the Figure 6-2 plots are based along with the percentage of holes through the upper GCL at the given time. See the response to NRC Action Item 12 (7/27/05) for additional information regarding the generation of these ranges of daily infiltration.

At year 0, with no holes through the upper GCL, infiltration through the upper GCL ranges from 0 to 0.0068 with an average of 0.0015 inches/day due to 0 to 6.87 inches of precipitation per day (see Table 6-2). At year 300, with holes in only 0.018 percent of the upper GCL, infiltration through the upper GCL ranges from 0 to 0.054 with an average of 0.013 inches/day due to this precipitation range (see Table 6-2). At year 1,800, the upper GCL has essentially failed hydraulically with holes in only 0.29 percent of the upper GCL, resulting in infiltration through the upper GCL ranging from 0 to 0.57 with an average of 0.067 inches/day due to this precipitation range (see Table 6-2). From this information the following two items are noted:

- Significant increases in daily infiltration through the upper GCL develop rapidly with the presence of very few holes in the upper GCL.
- Infiltration through the upper GCL increases with daily precipitation events that are greater than about one inch and/or with multiple consecutive days of precipitation.

Figure 6-2. Daily Infiltration as a Function of Daily Precipitation

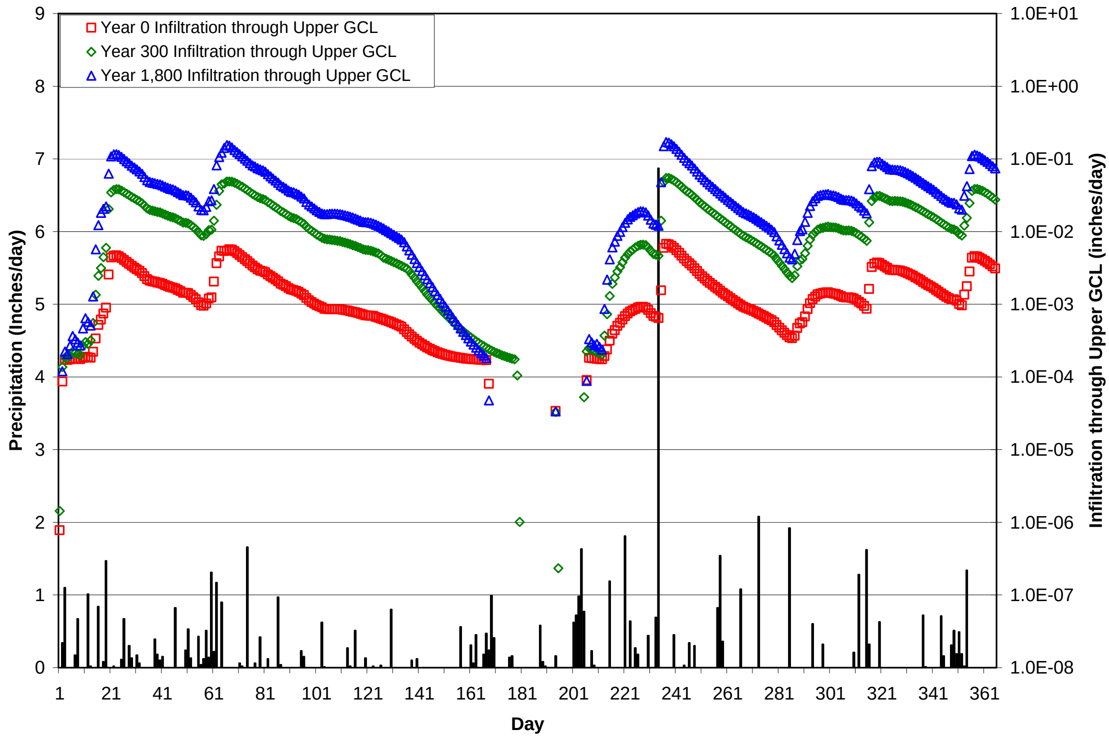

Table 6-2. Daily Precipitation and Daily Infiltration Data Statistics

Parameter	Daily Precipitation (in/day)	Daily Infiltration at Year 0 (in/day)	Daily Infiltration at Year 300 (in/day)	Daily Infiltration at Year 1,800 (in/day)
Maximum	6.87	0.0068	0.054	0.57
Average	0.17	0.0015	0.013	0.067
Minimum	0	0	0	0
Range	6.87	0.0068	0.054	0.57
Standard Deviation	0.50	0.0015	0.013	0.087
		Year 0	Year 300	Year 1,800
Percentage of GCL with holes (%)		0	0.018	0.29

Root Impact on the Lower Backfill, Lower Drainage Layer, and Lower GCL

Based upon the base case land use scenario, it is anticipated that after 10,000 years the depth to the top of the lower backfill (i.e., backfill directly below the upper GCL) will be 5.8 feet, the depth to the lower drainage layer will be 10.7 feet, and the depth to the lower GCL will be 12.7 feet (Phifer and Nelson 2003;

Tables 4.7-1 and 6.1-1, Phifer 2003; Tables 3.1-1 and 5.1-1). It is anticipated that pine tree roots will penetrate into both the lower backfill and lower drainage layers but not into the lower GCL. Root penetration into the lower GCL is not anticipated for the following reasons:

- It is located below the anticipated maximum pine tree root depth of 12 feet.
- The underlying concrete vault roof, together with the GCL, produces a hard, continuously saturated layer that will stop root elongation.

Therefore, no root impact to the lower GCL is anticipated. However, even though no degradation of the lower GCL is anticipated due to root penetration, current modeling (Cook et al. 2005; Section A.2.1) ignores the presence of the lower GCL altogether. Therefore, whether this lower GCL does or does not degrade over time is not relevant to the modeling. Although it is anticipated that pine tree roots will penetrate into both the lower backfill and lower drainage layer, it is not anticipated that such root penetration will provide a preferential flow path that will increase the infiltration to the top of the vault beyond that currently modeled with degradation of the upper GCL (see discussion above). The following are the reasons for this assumption:

- As discussed above, in general, the only hole produced in the ground due to the death and decomposition of a pine tree is associated with its conical shaped root mass, immediately below the trunk. Holes associated with the feeder root and tap root shrinkage and decomposition are not generally observed. These holes, in general, quickly fill with soil due to hydraulic and/or earth pressure induced soil movement.
- The estimated infiltration through the upper GCL is based upon the following very conservative assumptions as discussed in detail above:
    - Upon death of a tree, the tap root through the upper GCL is assumed to immediately disappear.
    - No GCL self-healing is assumed to occur in relation to root penetration.
    - Under saturated upper drainage layer conditions, cones of depression are assumed to be created around the holes in the GCL with a radius of influence much greater than the radius of the hole.
- The degraded closure cap average infiltration of approximately 14 inches/year after year 1,800 is in line with past background infiltration estimates made for areas in and around the Savannah River Site (SRS). Table 6-3 provides background infiltration estimates which have been made in general for relatively flat areas without closure caps. These background estimates are considered to be in good agreement with the degraded closure cap average of 14 inches/year, considering that the SDF

closure cap has a greater slope and a shorter slope length than considered for these background infiltration estimates.

Table 6-3. Infiltration Estimates at the Savannah River Site (SRS)

Source	Estimation Method	Estimated Average Infiltration (in/yr)
Hubbard 1986; page 2	Lysimeters	16
Parizek and Root 1986; page 4-38	Drainage basin hydrologic budget	15.62
Hubbard and Englehardt 1987; page 1	Modeling	14.7

Conclusions

Infiltration through the upper GCL of the SDF closure cap over time as determined by Phifer and Nelson 2003 and Phifer 2003 adequately represents fast pathways to the vault due to pine tree root penetration for the following reasons, as discussed in detail above:

- Holes associated with tap root shrinkage and decomposition are not generally observed due to relatively quick filling with soil due to hydraulic and/or earth pressure induced soil movement.
- Phifer and Nelson 2003 and Phifer 2003 made conservative assumptions to estimate infiltration through the upper GCL. It was assumed that upon death of a tree its tap roots through the upper GCL immediately disappeared and no GCL self-healing occurred. This resulted in an immediate direct conduit from the upper drainage layer to the lower backfill layer with a radius of influence much greater than the radius of the hole. This means that a small area of GCL holes greatly increased the vertical flow of water to the vault.
- On both an annual and daily basis, estimated infiltration through the upper GCL greatly increased with the presence of very few holes in the upper GCL as shown by Figures 6-1 and 6-2, respectively.
- Although there is no anticipated impact to the lower GCL due to root penetration, the lower GCL has been ignored within the current modeling (Cook et al. 2005; Section A.2.1).
- The estimated infiltration through the degraded SDF closure cap is in good agreement with SRS background infiltration estimates.

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Action Item 7 (7/27/05): ***Concrete and Saltstone Degraded Value Basis***

Provide a basis for degraded values of concrete and saltstone beyond professional judgment (RAI 32).

SRS Response: The 2005 Special Analysis (SA) (Cook et al. 2005) assumed that both the Saltstone and the vault structure would degrade over time. This was represented in the model by increasing the saturated hydraulic conductivity of these materials over the 10,000 year time of analysis. A broad range of degraded hydraulic conductivities for Saltstone and the vault were considered in the SA. Initial hydraulic conductivity for the vault is 1E-12 cm/s and is 1E-11 cm/s for the Saltstone. Both materials were degraded to hydraulic conductivities of 1E-09 cm/s. The sensitivity scenarios evaluated even higher hydraulic conductivities values up to 1E-06 cm/s.

Degradation mechanisms qualitatively considered for the concrete vault and the Saltstone waste form include:

- Cracking from seismic events and settlement
- Cracking due to external static loading (weight of overburden and cap)
- Chemical reactions involving the waste components in Saltstone which could result in expansion and cracking
- Chemical reactions involving ions in the soil which could result in expansion and cracking
- Chemicals reactions involving corrodents in the soil and soil pore water (i.e., acid rain) which could cause leaching and an increase in porosity
- Chemical reactions involving ions in the Saltstone which could cause leaching and an increase in porosity and/or cracking in the vault
- Physical process such as freeze-thaw cycles

The mechanisms for degradation of the buried waste disposal system (Saltstone and concrete vault) listed above, were grouped into conditions responsible for cracking and conditions responsible for removal of material, both of which will result in higher hydraulic conductivities of the system. Initially, cracking was assumed to be isolated and of little importance to the bulk hydraulic properties. Initial leaching was also assumed to be local and confined to the outer surface. Cracking and interconnectivity of the cracks and increase in porosity due to leaching were assumed to increase with time. The consequences of progressive cracking with respect to providing path ways for increased water flow were assumed to be limited by the confined conditions (overburden and consolidated soil) of the Saltstone and vault.

Consequently, the bases for the assumptions concerning the increase in hydraulic conductivity over time as the result of degradation of the concrete vault and Saltstone waste form are:

- An assessment of potential degradation mechanisms. (Information from the concrete and waste form literature was used to identify mechanisms. (see responses to NRC RAIs 32, and 43))
- A simplified assessment of the consequences of these mechanisms (cracking and leaching).
- The vault and waste form remain buried (confined) over the period of performance, therefore, freeze/thaw and erosion were not considered.
- External factors associated with environmental conditions such as climate (acid rain), chemistry of infiltrating water (limited leaching by introduction of new corrodents) would be significantly less than the effects of cracking over the period of performance.
- The timing for the increase in hydraulic conductivity over the period of performance in the SA was considered as a multiple step function, with the steps tied to degradation of the cap (see Appendix A in the 2005 SA).

The highest saturated hydraulic conductivity used in the 2005 SA was 1E-09 cm/s for both the vault and Saltstone. In the sensitivity cases requested by the NRC, the range was extended to 1E-06 cm/s. A value of 1E-06 cm/s is representative of a clayey-sand soil that can be found at the Savannah River Site. The sensitivity cases that assumed the higher hydraulic conductivities of either Saltstone and/or the vault are very conservative. (See response to NRC Action Item 10 (8/17/05) sensitivity cases 23, 27, 28, 30, and 33).

A number of sensitivity cases have been run in response to questions raised in the review of the Salt Disposal program that focused on this topic. Final saturated hydraulic conductivities ranging from 1E-8 to 1E-6 cm/s were used to investigate the effect this change had on the calculated all-pathways dose. These cases showed that there is an increase in the calculated dose as the degradation rates increase. However, over the range of values considered, the calculated doses were still below the performance objective.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 8 (7/27/05): ***Assessment of Flow Through Fractures***

Provide an assessment of flow through fractures considering realistic conditions (e.g., seismically-induced offset, variability in moisture, infilling of fractures) (RAI 36).

SRS Response: Uncertainties in the properties of saltstone, the vault, and surrounding geologic materials create uncertainty in matric suction and saturation in saltstone and adjoining materials. Lower matric suction in saltstone compared to the base case modeling prediction could produce increased advective flow through porous saltstone, and/or activate fracture flow through macroscopic cracks resulting from differential settlement and seismic events. Similarly, temporal and/or spatial variations in infiltration, seismically-induced offset, and infilling of fractures could potentially activate fracture flow. Rather than considering each of these phenomena and combined effects in a detailed mechanistic analysis, two additional sensitivity runs were performed to assess the potential impact on dose.

In sensitivity case 31, discussed in the response to U. S. Nuclear Regulatory Commission (NRC) Action Item 10 (8/17/05) contained within this document, the vault and saltstone are assumed to exhibit large-scale through-cracks at a 30-ft spacing. For comparison, the best-estimate settlement/seismic crack spacing averages 200 ft, i.e., three transverse cracks over a 600-ft length (Peregoy 2003). Cracks are represented by two-feet wide columns of gravel in the numerical model. Secondly, the vault, saltstone, and cracks are assumed to be fully-saturated. The latter is implemented in the numerical model by setting the water retention and relative permeability curves to 1.0 regardless of suction (i.e., the saturated conductivity value is used under both unsaturated and saturated conditions). These pessimistic assumptions maximize advective flow through porous saltstone, and, more importantly, force flow through the postulated fractures. The result is an increase in dose from 0.05 mrem/yr to 3.5 mrem/yr in comparison to the base case (sensitivity case 1 from the response to NRC Action Item 10 (8/17/05)). For reference, the performance objective for the facility is a dose not exceeding 25 mrem/yr.

A second sensitivity case was run to specifically explore the impact of fractures infilled with granular material. This sensitivity case is not one of the 33 cases discussed in the response to NRC Action Item 10 (8/17/05). In this sensitivity case, a conservative 30 ft crack spacing was assumed as in sensitivity case 31 discussed above. Infilled cracks were represented by two-foot columns of native soil in the numerical model to accommodate the existing mesh resolution, and result in a conservative representation of physical cracks with a nominal aperture of roughly one inch. The baseline moisture curves were used for all materials. The result is an increase in dose from 0.05 mrem/yr to 1.1 mrem/yr in comparison to the base case (sensitivity case 1 from the response to NRC Action Item 10 (8/17/05)). The performance objective for the facility is a dose not exceeding 25 mrem/yr.

In summary, the sensitivity cases discussed above, fully saturated cracks and cracks infilled with granular material, are conservative and show that the all-pathways doses are still well below the performance objective of a dose not exceeding 25 mrem/yr. No further detailed analyses are warranted.

References:

Peregoy, W., 2003, *Saltstone Vault Structural Degradation Prediction*, T-CLC-Z-00006, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 9 (7/27/05): ***Reducing Conditions of the Saltstone Wasteform***

Provide any additional information to support reducing conditions of the saltstone wasteform considering cracking and oxygen transport in the gas phase (RAI 41, 55).

SRS Response: The latest laboratory measurement of the reduction capacity of slag was issued by Savannah River National Laboratory (SRNL; Kaplan et al. 2005) and it agrees very well with values previously reported by Lawrence Berkeley National Laboratory (LBNL; Lukens et al. 2005). SRNL reported that the slag reduction capacity was 0.817 ± 0.001 meq/g (Kaplan et al. 2005; page 9), whereas the LBNL reported the slag reduction capacity was 0.821 meq/g (Lukens et al. 2005; page 6). Technically, these are treated as identical values. They also reflect high reduction capacities, especially when compared to the reduction capacity of native Savannah River Site (SRS) sediments, 5.1E-3 meq/g (Kaplan et al. 2005; page 9).

More compelling evidence in support of the contention that slag saltstone maintains a reducing environment is presented in Figure 9-1 from the 1992 Performance Assessment (MMES 1992; page 2-54). As shown in the figure, no Tc-99 leached for 2.5 years from a field lysimeter containing slag saltstone (open circles), but did leach from a lysimeter containing saltstone without slag (filled circles).

In a recent report evaluating the reducing-capacity longevity of the reducing grout used to stabilize a high-level tank heel, scenarios were included in which cracks and oxygen transport in the aqueous and gas phases were considered (Kaplan et al. 2005). In the simulations, oxygen from the gas phase was permitted to come into equilibrium with oxygen in the vadose zone groundwater. The vadose zone water would in turn enter the tank that was filled with reducing grout through advection and diffusion processes. The slag added to the grout in this scenario will be the same as that used in the saltstone. Figure 9-2 shows some simulations of the slag reduction capacity in a tank with three hypothetical cracks (3-cm wide) present during the entire simulation. In these plots, red signifies reducing conditions and blue signifies oxidizing conditions. After 10,000 years, 8% of the reducing grout became oxidized, as shown by areas other than red. After 50,000 years, 32% of the reducing grout became oxidized. After 10,000 years, with 0, 1, and 3 cracks in the tank, 5%, 5%, and 8% of the reducing grout became oxidized respectively (Figure 9-3).

In summary, these additional data support the contention that reduction capacity is high in materials containing the SRS slag. They also show that the reduction capacity of these materials is expected to exist for a long duration in the SRS subsurface environment. Furthermore, they show that the movement of gaseous oxygen through pore spaces will likely contribute to the consumption of slag reduction capacity by constantly replenishing the dissolved oxygen content of groundwater, but the total consumption of reduction capacity by this process ($O_{2(g)} \rightarrow O_{2(aq)}$, then $O_{2(aq)}$ consumes reductant) is very slow, largely due to slow diffusional movement of oxygenated water.

Sensitivity analysis performed to quantify the impact of the reducing conditions of the saltstone wasteform is provided in the response to U. S. Nuclear Regulatory Commission (NRC) Action Item 10 (8/17/05) contained within this document. The sensitivity cases associated with variations in the reducing conditions of saltstone are sensitivity cases 21, 22, 29, 30, 32 and 33.

Figure 9-1. Comparison of technetium vs. nitrate leaching from slag- and cement based saltstone lysimeters (MMES 1992)

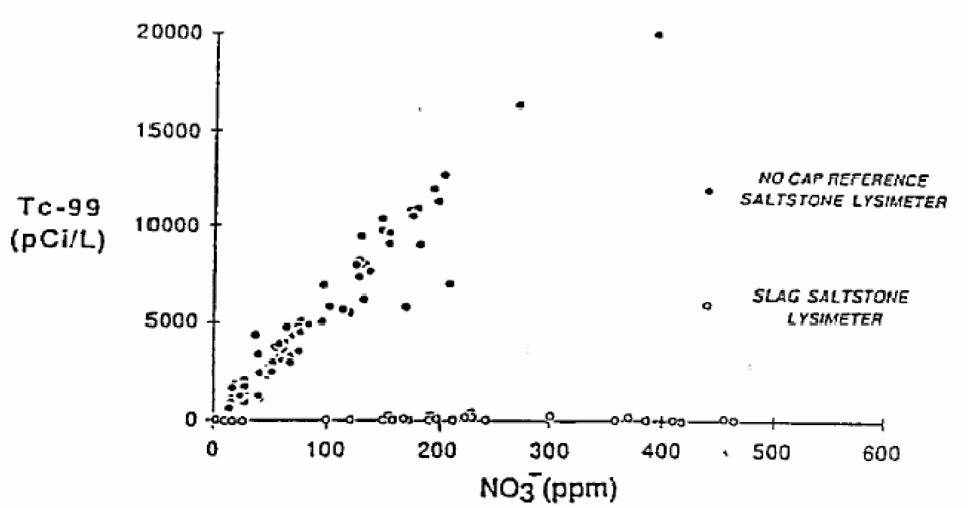


Figure 9-2. Slag reduction capacity (meq g^{-1}) at 0 (top plot), 10,000 (middle plot), and 50,000 (bottom plot) years, respectively in a high-level SRS waste tank; red = most reduced, blue = most oxidized; half a tank is shown (Kaplan et al. 2005).

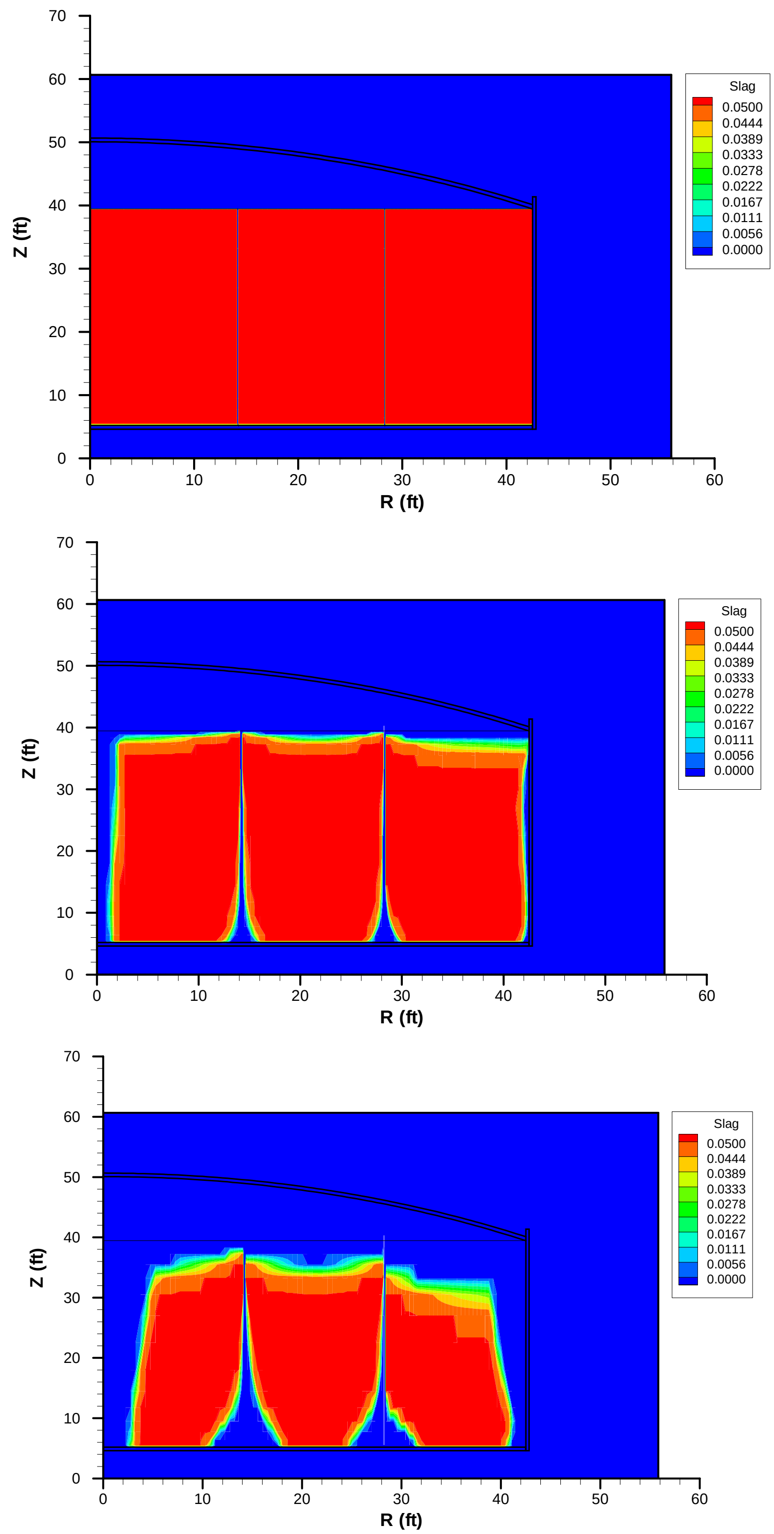
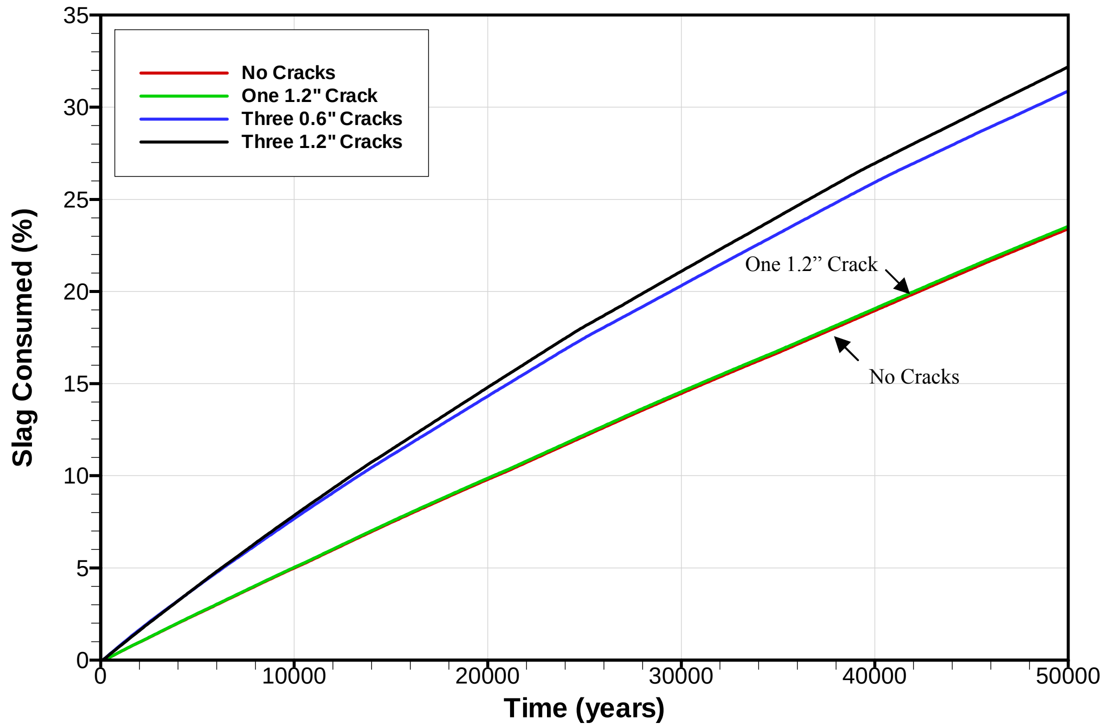


Figure 9-3. Tank slag capacity consumed (based on calculations similar to Figure 9-2; Kaplan et al. 2005; Table 35)



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Action Item 10 (7/27/05)***: Explanation of Findings from WSRC-TR-2005-00114***

Explanation of why findings in April 2005 report (WSRC-TR-2005-00114) do not invalidate DOE's conclusions that in-tank treatment of Tank 48 waste is not feasible (RAI#13).

SRS Response: Performance of Fenton's In-Situ was considered in the recent *Re-Evaluation of Tank 48 Disposition Alternatives* (Maxwell 2005). In the final ranking of the thirteen alternatives evaluated, the two options which utilized the Fenton's In-situ process ranked at the bottom (12 and 13). The Fenton's In-Situ process was ranked low because of relatively low ratings for Technical Maturity (no testing with actual waste and testing to date is only on a laboratory scale) and System Impacts (potential for degradation to the tank since previous simulant testing indicated potential for pitting corrosion) (Zapp and Mickalonis 2004).

Recent laboratory simulant testing reported in WSRC-TR-2005-00114 (Lambert et al. 2005) was conducted for the Fenton's In-situ process. These results were considered as part of the Tank 48 re-evaluation rankings.

The results of this testing contained no new information which would increase the ratings given to the Fenton's In-Situ process from previous evaluation (Dean 2004) nor during the re-evaluation of Tank 48 disposition alternatives. Although recent laboratory simulant testing (Lambert et al. 2005) indicates that there is a potential for the Fenton's Reagent process to be successful at an in-situ condition of pH 11, the tests did not provide a measure for pitting corrosion. The report estimates the general corrosion rate using the carbon steel reaction vessel as a large corrosion coupon. The general corrosion rate equaled 3.7 mil/year at pH 11, which is a similar general corrosion rate determined from previous corrosion testing (Zapp and Mickalonis 2004). Pitting was not evaluated in the recent laboratory simulant testing (Lambert et al. 2005) and remains an issue. The testing report notes that the corrosion rate appears *"manageable"* based on general corrosion rates. As noted in the report, in order to implement the Fenton's In-Situ option additional testing to determine the parameters/inhibitor additions necessary to prevent pitting corrosion must be completed, testing with actual Tank 48H waste must be performed using the proper corrosion inhibitor, and experiments must be conducted to finalize the flowsheet.

References:

Lambert, D. P., Peters, T. B. and Fink, S.D., 2005, *In-Tank Peroxide Oxidation Process For The Decomposition Of Tetraphenylborate In Tank 48H*, WSRC-TR-2005-00114, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Maxwell, D., 2005, *Re-Evaluation of Tank 48H Disposition Alternatives,* CBU-PIT-2005-00147, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Zapp, P. E. and Mickalonis, J. I., 2004, *Electrochemical Tests of Carbon Steel in Simulated Waste Containing Fenton's Reagent*, WSRC-TR-2003-00445, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Dean, W. B., 2004, *Tank 48 Disposition Project WSRC In-House Treatment Option Evaluation*, G-ADS-H-00007, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 11 (7/27/05): ***Sampling Plan for Waste sent to SPF***

Provide sampling plan for waste sent to Saltstone Production Facility (RAI 16).

SRS Response: *Sampling Strategy for Tank 50 Point of Compliance Transfers to Saltstone* (Ketusky 2005) provides the sample strategy to support waste transfers from Tank 50 to the Saltstone Production Facility. A copy of the sampling plan is included with this submittal.

References:

Ketusky, E. T., 2005, *Sampling Strategy for Tank 50 Point of Compliance Transfers to Saltstone*, CBU-PIT-2005-00014, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 12 (7/27/05): ***Precipitation and Infiltration Rates to Cap***

Provide information on the range of precipitation and infiltration rates with regard to the cap (RAI 20).

SRS Response: As outlined in the Savannah River Site (SRS) response to the U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) Comment 20 (WSRC 2005), a 100-year synthetically generated precipitation data set, along with the degraded closure cap material property data sets, were utilized as input to the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994a and USEPA 1994b) to determine the average annual infiltration through the upper geosynthetic clay liner (GCL) for each year modeled since closure. Subsequently, the average annual infiltration through the upper GCL for each year modeled was then utilized as the upper flow boundary condition for the vadose zone PORFLOW modeling performed within Cook et al. 2005, Section A.2. In response to this NRC Action Item, the relationships of annual infiltration to annual precipitation and daily infiltration to daily precipitation have been evaluated for the HELP model runs utilized to determine the average annual infiltration through the upper GCL.

Annual Infiltration to Annual Precipitation Relationship

The range of annual infiltration that could result from annual precipitation ranging from approximately 30 to 70 inches/year has been determined for each year previously modeled (i.e., 0, 100, 300, 550, 1,000, 1,800, 3,400, 5,600, and 10,000). Figure 12-1 provides a pictorial description of the 100-year synthetically generated precipitation data set utilized along with the 35-year SRS F-Area Weather Station precipitation data upon which it is derived. Table 12-1 provides a statistical description of this 100-year synthetically generated precipitation data set. Generation of this data set is discussed within Phifer and Nelson 2003. The HELP model runs, from which the information has been extracted, are the same as those previously utilized to supply average annual infiltration through the upper GCL for the vadose zone PORFLOW modeling performed by Cook et al. 2005. However, annual infiltration through the upper GCL resulting from annual precipitation ranging from approximately 30 to 70 inches/year has been extracted from the results.

Figures 12-2 through 12-10 provide the potential range of annual infiltration through the upper GCL resulting from 30 to 70 inches/year of annual precipitation for each year modeled (i.e., 0, 100, 300, 550, 1,000, 1,800, 3,400, 5,600, and 10,000). Table 12-2 provides the statistics associated with the precipitation and infiltration data. Table 12-3 provides the best fit linear regression equation and the associated coefficient of determination, R^2, for annual infiltration through the upper GCL as a function of annual precipitation for each year modeled. Figure 12-11 provides plots of annual infiltration as determined from the associated linear regression equations over an annual precipitation range of 30 to 70 inches/year for each year modeled.

As shown by this data, infiltration through the upper GCL ranges from 0.13 to 0.73 inches/year with an average of 0.36 inches/year due to 30 to 70 inches of precipitation per year (see Table 12-2), with the initial conditions of the upper GCL and upper drainage layer. However, as the upper GCL and upper drainage layer degrade, the range of infiltration produced by this precipitation range increases (see Figures 12-1 thru 12-10 and Figure 12-11). At year 1,800, the upper GCL and upper drainage layer have essentially failed hydraulically and infiltration through the upper GCL ranges from 3.1 to 30.6 inches per year with an average of 13.8 inches/year due to this precipitation range (see Table 12-2).

Table 12-1. Precipitation Data Statistics for the 100-year Synthetically Generated Precipitation Data Set

Parameter	Average	Median	Standard Deviation	Minimum	High
Daily Precipitation (inches)	0.13	0.00	0.37	0.00	6.87
Yearly Precipitation (inches)	48.96	48.83	7.74	29.28	68.99

Figure 12-1. 100-year Synthetically Generated Precipitation Data Set

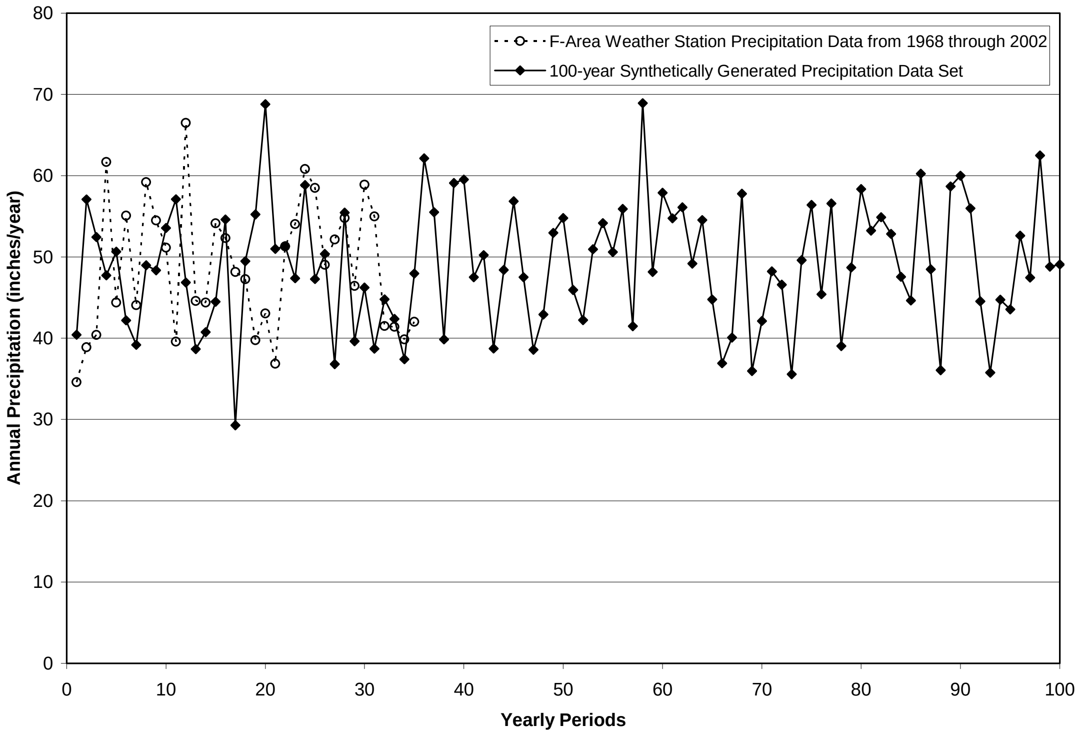


Figure 12-2. Potential Infiltration through the Upper GCL for an Intact Closure Cap (Year 0)

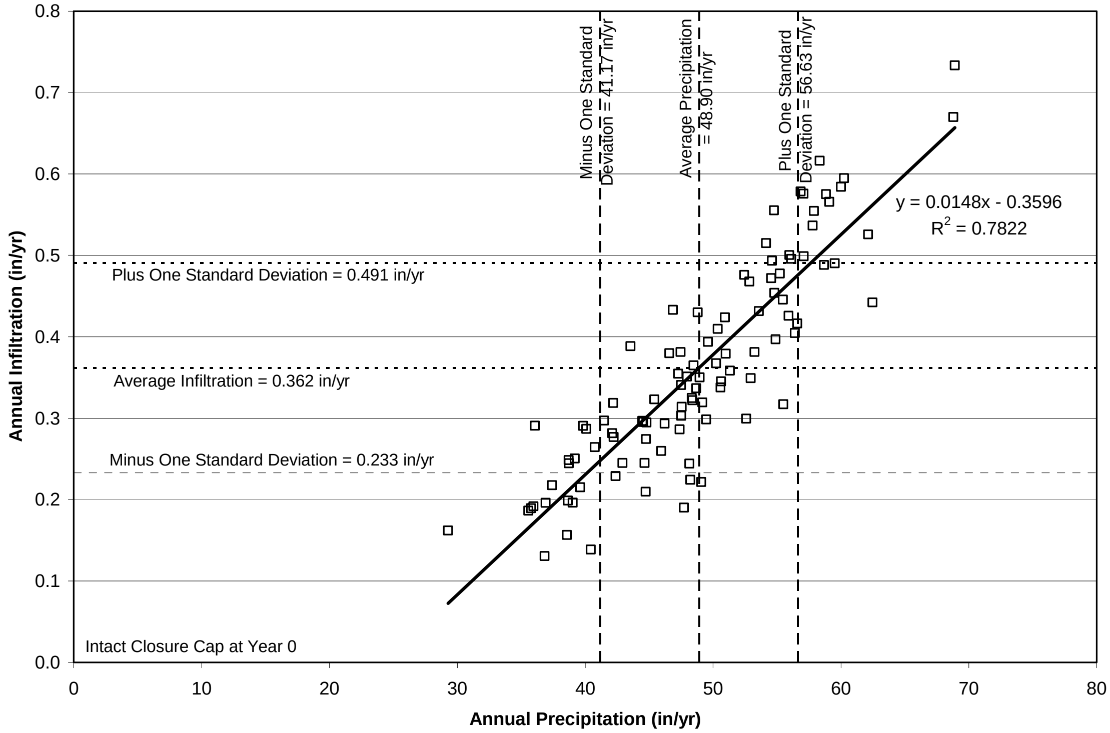


Figure 12-3. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 100)

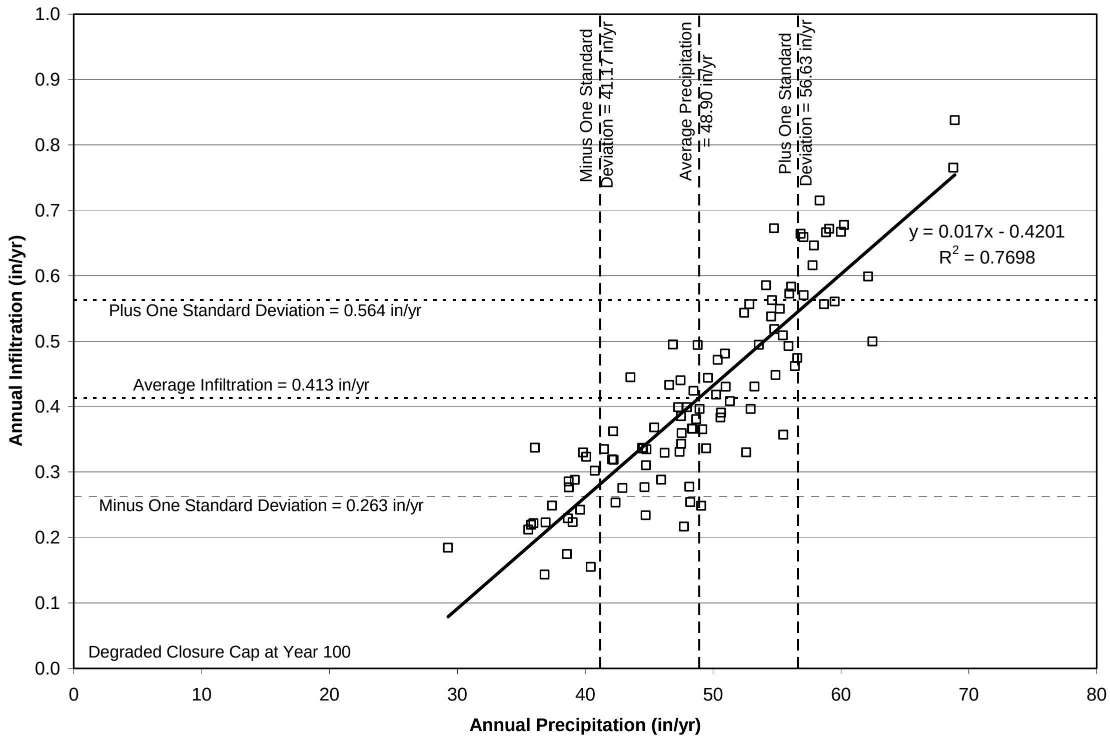


Figure 12-4. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 300)

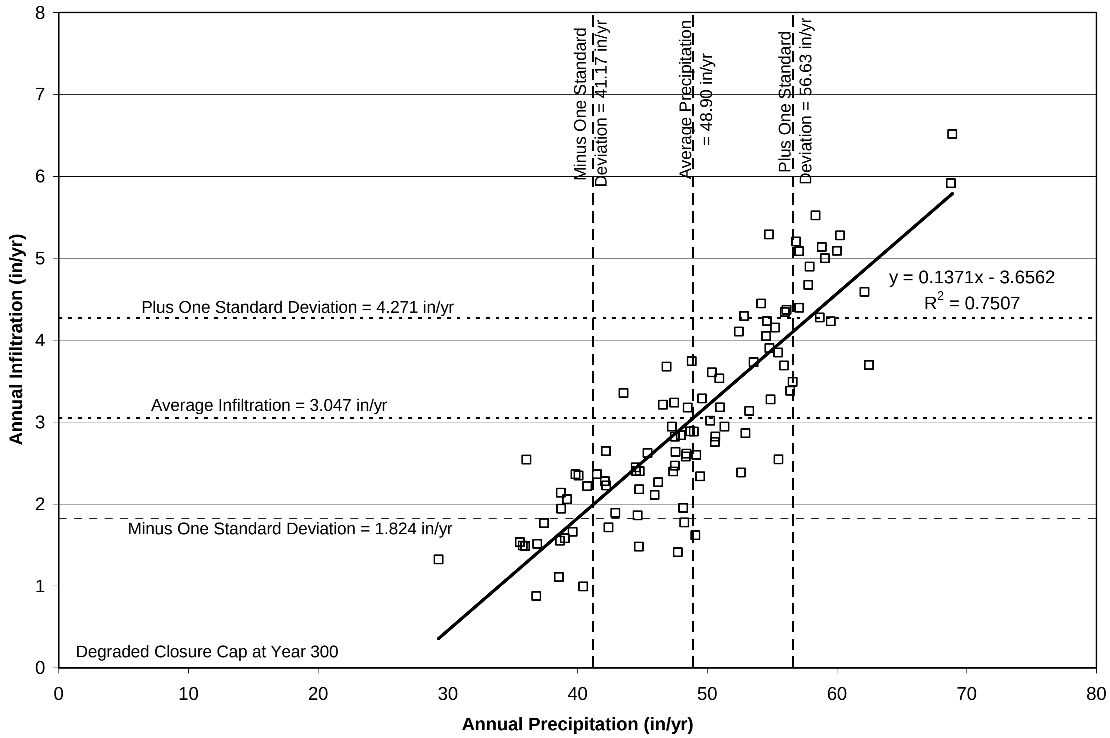


Figure 12-5. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 550)

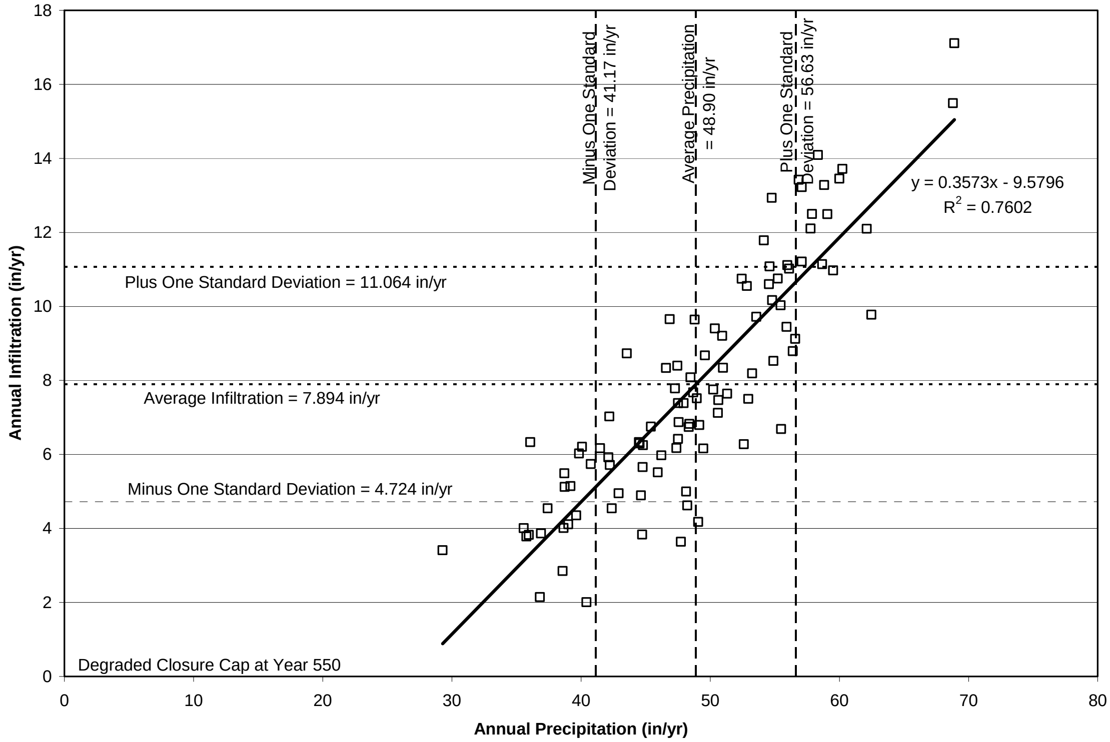


Figure 12-6. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 1,000)

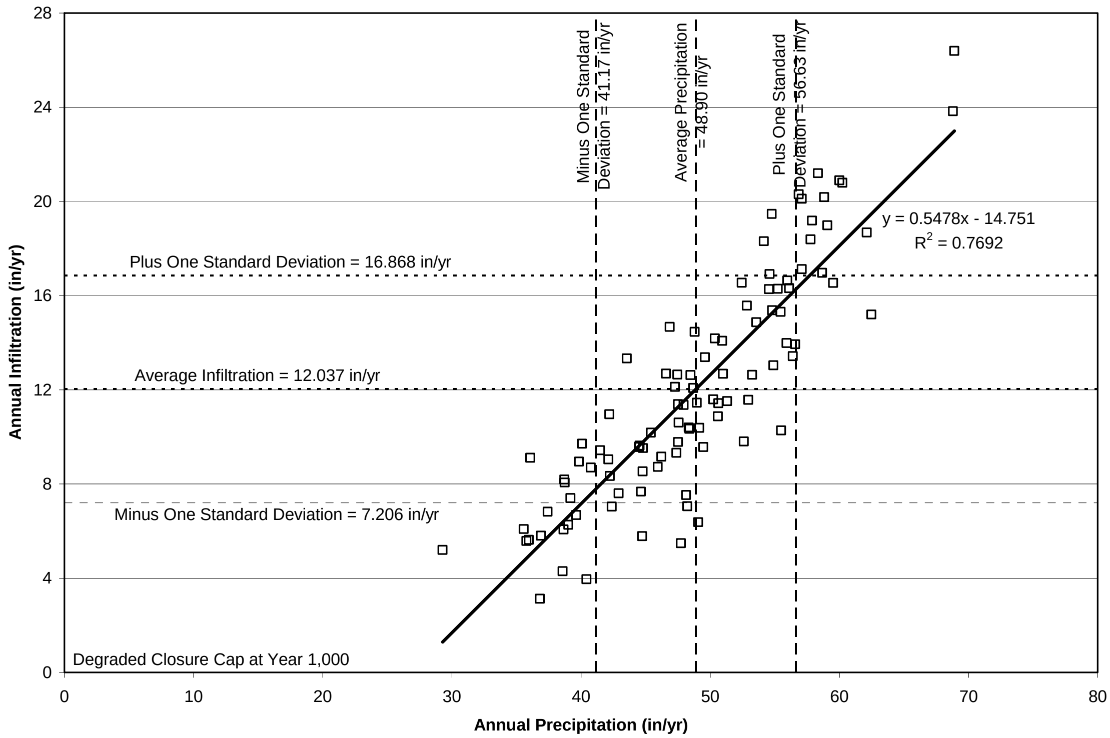


Figure 12-7. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 1,800)

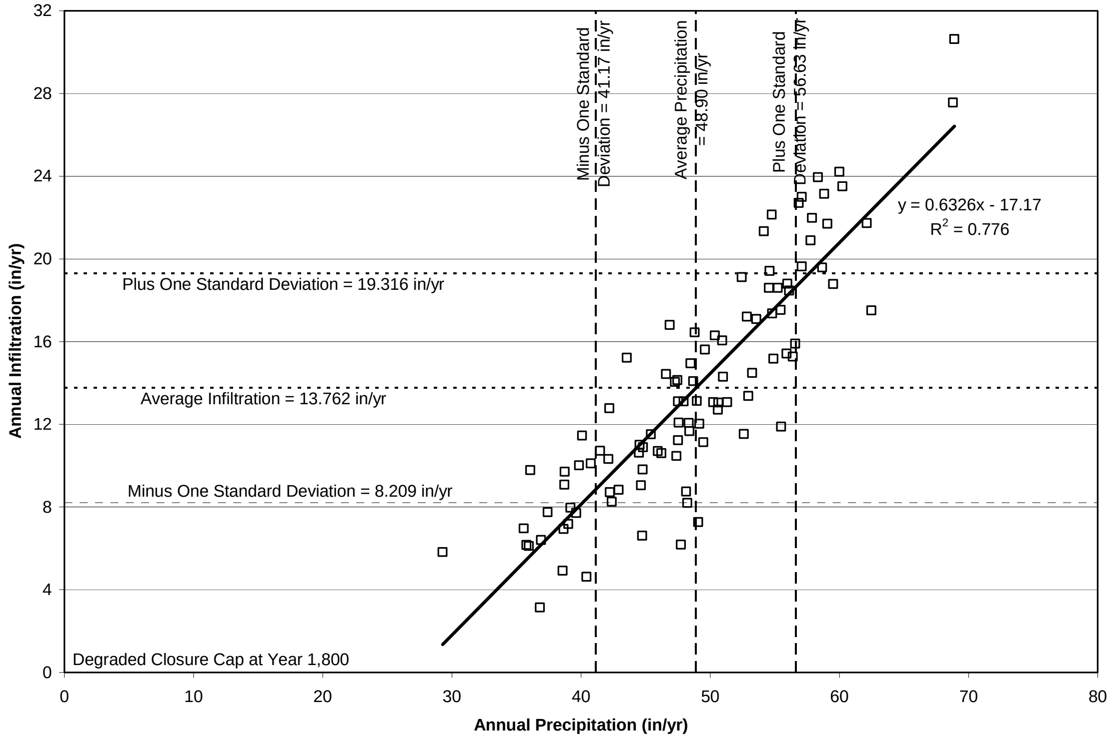


Figure 12-8. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 3,400)

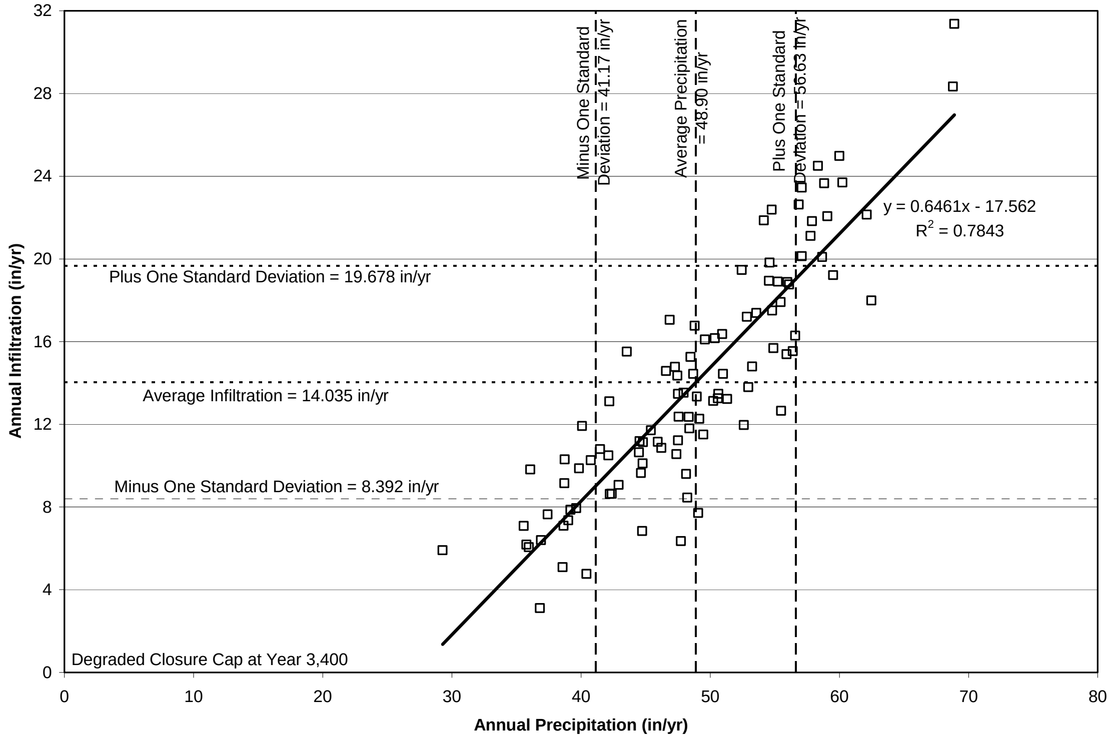


Figure 12-9. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 5,600)

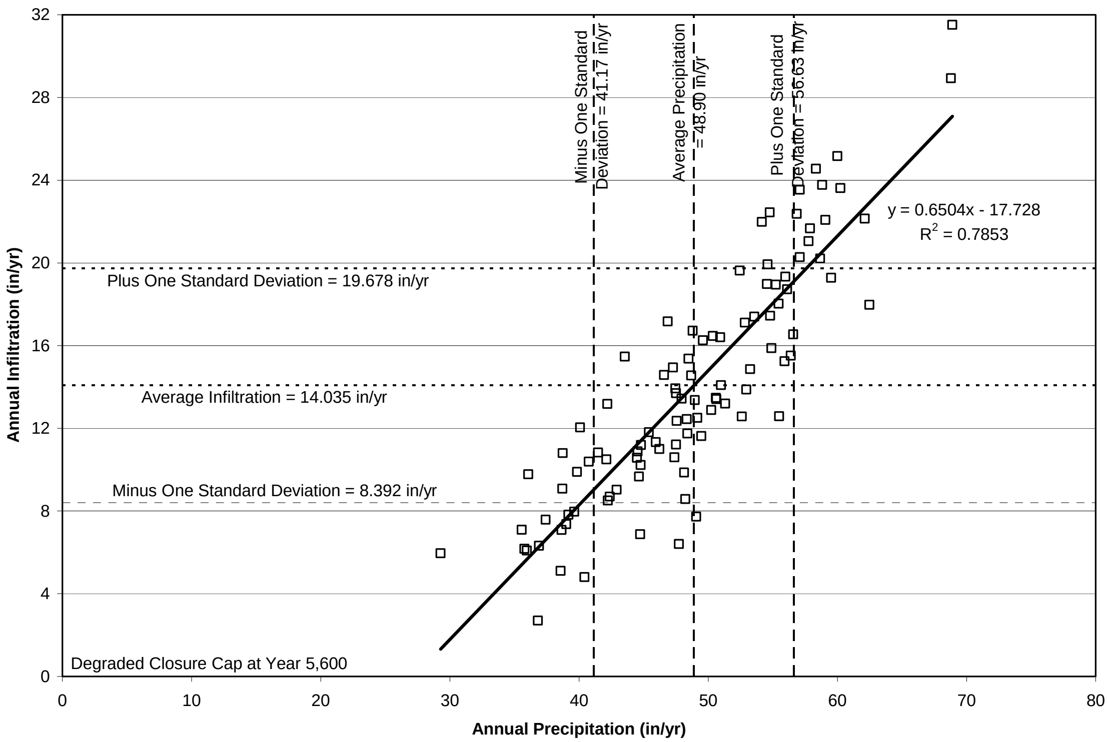


Figure 12-10. Potential Infiltration through the Upper GCL for a Degraded Closure Cap (Year 10,000)

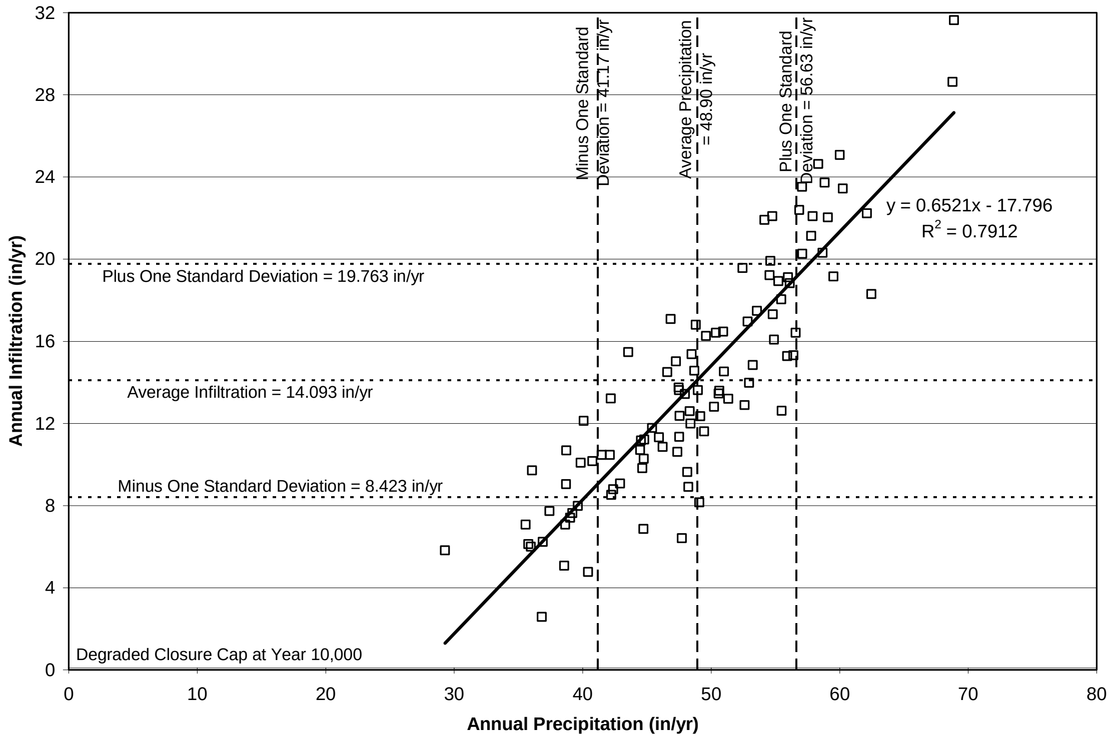


Figure 12-11. Comparative Infiltration as a Function of Precipitation for each Modeled Year

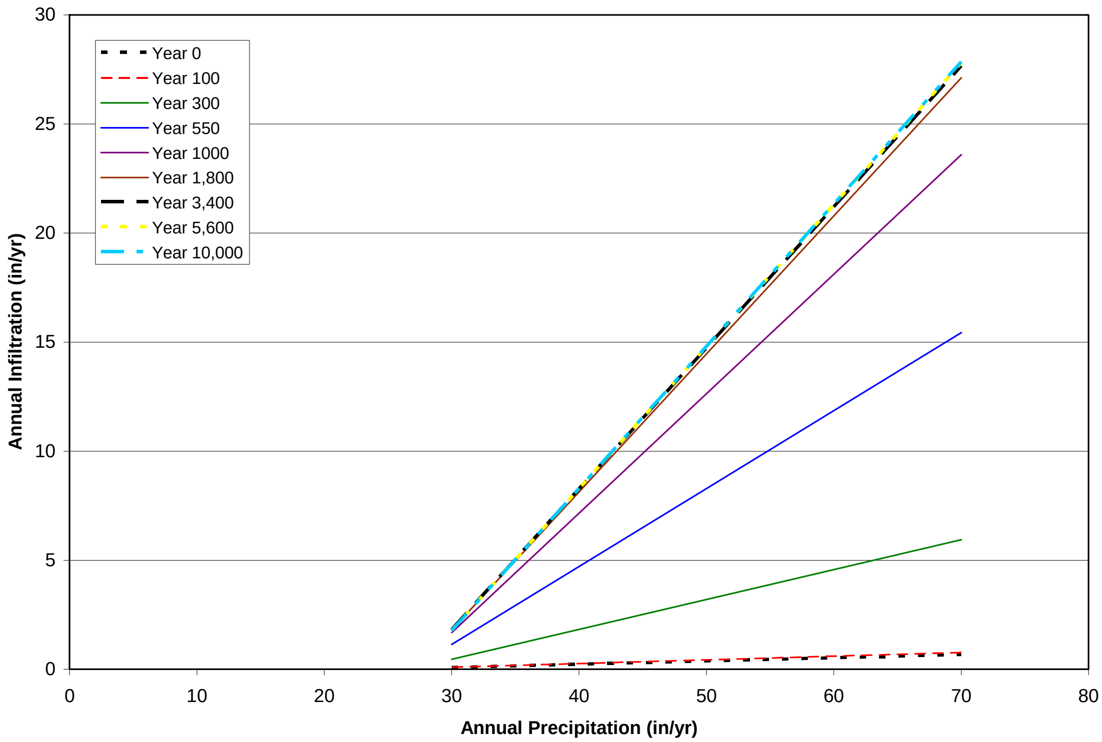


Table 12-2. Annual Precipitation and Annual Infiltration Data Statistics

Parameter	Annual Precipitation (in/yr)	Annual Infiltration at Year 0 (in/yr)	Annual Infiltration at Year 100 (in/yr)	Annual Infiltration at Year 300 (in/yr)	Annual Infiltration at Year 550 (in/yr)
Maximum	68.90	0.733	0.838	6.516	17.111
Average plus 1 Standard Deviation	56.63	0.491	0.564	4.271	11.064
Average	48.90	0.362	0.413	3.047	7.894
Median	48.59	0.343	0.388	2.831	7.425
Average minus 1 Standard Deviation	41.17	0.233	0.263	1.824	4.724
Minimum	29.28	0.131	0.143	0.878	2.006
Range	39.62	0.60	0.69	5.64	15.10
Standard Deviation	7.73	0.129	0.150	1.224	3.170
Parameter	Annual Infiltration at Year 1,000 (in/yr)	Annual Infiltration at Year 1,800 (in/yr)	Annual Infiltration at Year 3,400 (in/yr)	Annual Infiltration at Year 5,600 (in/yr)	Annual Infiltration at Year 10,000 (in/yr)
Maximum	26.392	30.632	31.366	31.510	31.633
Average plus 1 Standard Deviation	16.868	19.316	19.678	19.756	19.763
Average	12.037	13.762	14.035	14.079	14.093
Median	11.415	13.069	13.298	13.388	13.442
Average minus 1 Standard Deviation	7.206	8.209	8.392	8.402	8.423
Minimum	3.133	3.144	3.112	2.699	2.578
Range	23.26	27.49	28.25	28.81	29.06
Standard Deviation	4.831	5.553	5.643	5.677	5.670

Table 12-3. Annual Infiltration as a Function of Annual Precipitation

Year	Linear Regression Equation	R^2
0	$I = 0.0148P - 0.3596$	0.7822
100	$I = 0.017P - 0.4201$	0.7698
300	$I = 0.1371P - 3.6562$	0.7507
550	$I = 0.3573P - 9.5796$	0.7602
1,000	$I = 0.5478P - 14.751$	0.7692
1,800	$I = 0.6326P - 17.17$	0.776
3,400	$I = 0.6461P - 17.562$	0.7843
5,600	$I = 0.6504P - 17.728$	0.7853
10,000	$I = 0.6521P - 17.796$	0.7912

I = annual infiltration; *P* = annual precipitation

Daily Infiltration to Daily Precipitation Relationship

The HELP model was rerun for the intact closure cap case (year 0) and the 10,000 year degraded case utilizing the precipitation data from a single year in order to obtain daily precipitation and infiltration data. The precipitation data from the year with the day of greatest precipitation (i.e., 6.87 inches/day) from the 100-year synthetically generated precipitation data set was utilized. This precipitation data set had a total yearly precipitation of 61.33 inches, a range of precipitation from 0 to 6.87 inches/day, an average daily precipitation of 0.17 inches (see Table 12-4), and the precipitation pattern and intensity shown in Figure 12-12. For the intact closure cap case (year 0), this resulted in the daily infiltration through the upper GCL shown in Figure 12-12. For the intact case the resulting daily infiltration ranged from 0 to 0.0068 with an average of 0.0015 inches/day due to 0 to 6.87 inches of precipitation per day. For the 10,000-year degraded case, this resulted in the daily infiltration through the upper GCL shown in Figure 12-13. For the 10,000-year degraded case, the resulting daily infiltration ranged from 0 to 1.56 with an average of 0.064 inches/day due to 0 to 6.87 inches of precipitation per day. However, no discernable functional relationship could be established between precipitation and infiltration on a daily basis, as could be determined on an annual basis, due to the many processes which are very dynamic on a daily basis as compared to an annual basis. However, it is clear from Figures 12-12 and 12-13 that infiltration through the upper GCL increases with daily precipitation events greater than about one inch and/or multiple consecutive days of precipitation.

Table 12-4. Precipitation Data Statistics for the Year with a Precipitation of 61.33 inches

Parameter	Average	Median	Standard Deviation	Minimum	Maximum
Daily Precipitation (inches)	0.17	0	0.50	0	6.87

Figure 12-12. Intact Closure Cap with 61.33 inch Yearly Precipitation Data Set

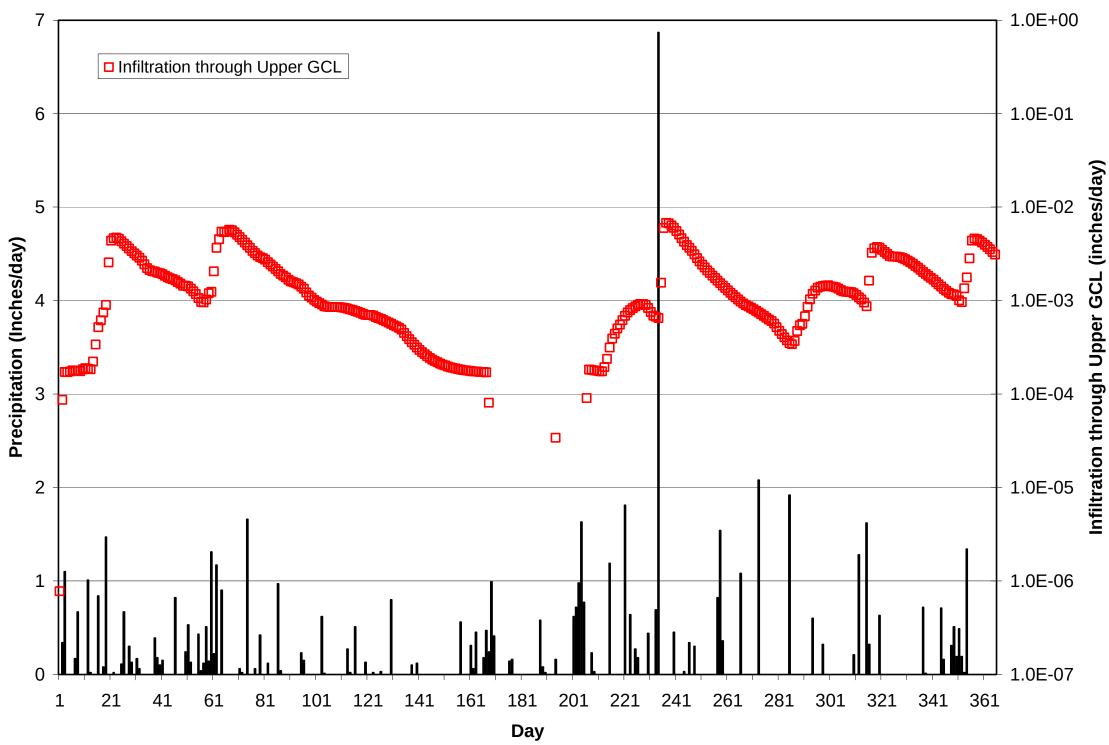
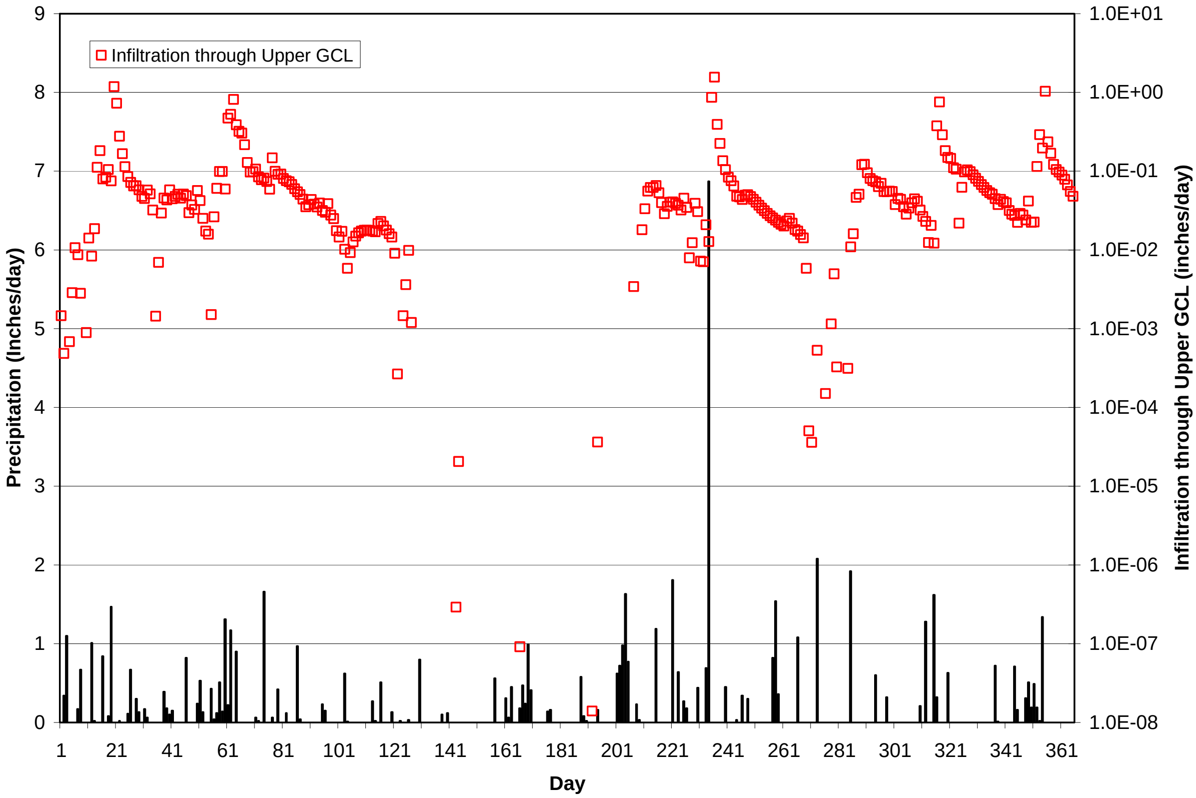


Figure 12-13. 10,000 Year Closure Cap with 61.33 inch Yearly Precipitation Data Set



Sensitivity analysis performed to quantify the impact of precipitation and infiltration rates with regard to the cap is provided in the Response to U. S. Nuclear Regulatory Commission (NRC) Action Item 10 (8/17/05) contained within this document. The sensitivity cases associated with variations in the precipitation and infiltration rates are sensitivity cases 24, 25, 30 and 33.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. and Nelson, E. A., 2003, *Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U)*, WSRC-TR-2003-00436, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

USEPA (U.S. Environmental Protection Agency), 1994a, *The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3*, EPA/600/R-94/168a, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency), 1994b, *The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3*, EPA/600/R-94/168b, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

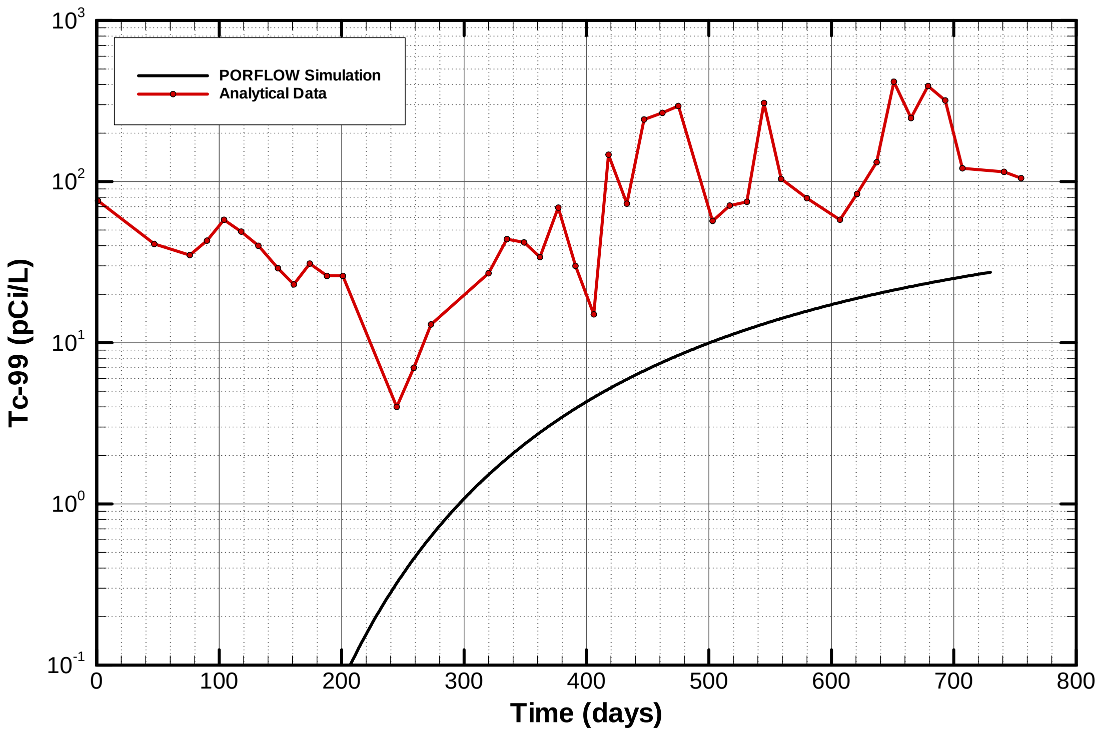
WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 13 (7/27/05): *Comparison of Slag Data*

Provide a comparison of the slag data on a non-linear scale or in tabular form (RAI 31).

SRS Response: Figure 13-1 below presents the data from the Saltstone Slag lysimeter and the PORFLOW simulation of the slag lysimeter on an expanded scale. The plot shows that the results of the PORFLOW simulation are less than the slag lysimeter results. This is because the measurements from the saltstone lysimeters were not specific for Tc-99. Rather, the measurements were for gross non-volatile beta-gamma emitters (i.e., the sample was evaporated onto a planchet and counted without energy discrimination). The results shown are essentially background, which is consistent with the PORFLOW simulation.

Figure 13-1.



Action Item 14 (7/27/05): ***Reference for Malek Data***

Provide identification of reference for Malek data and whether Malek data was considered in defining degraded value for concrete and saltstone (RAI 33).

SRS Response: *Source of Information in RAI 33, Table 33-1*

An additional reference for the source of information in Table 33-1 of the response to U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) Comment 33 (WSRC 2005) is provided in *Saltstone Physical and Mechanical Properties* (Licastro et al. 2005). The information (reproduced below) can be found on page 11, column labeled permeability (Mix 84-45).

The data in Table 33-1 of the response to NRC RAI Comment 33 for Mix 84-48 were incorrectly identified as applicable for a slag containing mix. The data were for mix 84-47 which was not a slag mix. The data shown for 84-48 mix will be removed from Table 33-1.

Use of Malek data and Licastro et al. data

The Malek data (Malek et al. 1985) is for saltstone formulations considered prior to development of the final saltstone grout formulation. Since the Core Laboratories data (Yu et al. 1993) was for the final formulation, the Core Laboratories data was used in the 2005 Special Analysis (Cook et al. 2005).

Table 9. Physical Properties (84-45).

Curing Time (days)	Compressive Strength MPa/psi	Dynamic Modulus (10^6 psi)	Bulk Density (g/cc)	Bulk Porosity (%)	Hg Intrusion Porosity (%)	Length Change Δl/l (%)	Permeability (Darcy)
7	8.91/1292	1.07	1.33	40		0.000	2.46×10^{-3} 5.30×10^{-7}
28	18.30/2654	1.38	1.33	43	42.5	0.200	$<10^{-8}$
56	21.40/3104	1.36	1.41	34	45.4	0.230	$<10^{-8}$ 1.60×10^{-6}
90	22.82/3309	--	1.31	43	44.4	0.240	1.49×10^{-5}
180	24.12/3498	1.39	1.29	44	42.5	0.244	6.42×10^{-8} 3.28×10^{-6}
360	24.46/3547	1.22	1.30	45	43.7	0.250	2.4×10^{-5}

(Licastro et al. 2005).

References: Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Licastro, P. H., Roy, D. M., and Malek, R. A. I., 2005, *Saltstone Physical and Mechanical Properties*, WSRC-RP-2005-01733, submitted to E. I. du Pont de Nemours and Company, December 1985, Westinghouse Savannah River Company, Aiken, South Carolina.

Malek, R., Roy, D. M., Barnes, M. W. and Langton, C. A., 1985, *Slag Cement –Low Level Waste Forms at the Savannah River Plant, DP-MS-85-9,* E. I. DuPont de Nemours and Company.

Yu, A. D., Langton, C. A. and Serrato, M. G., 1993, Physical Properties Measurement Program (U), WSRC-RP-93-894, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 15 (7/27/05): *Moisture Curve Generation Data*

Provide a description of use of data in generating moisture curves considering the identified errors in the collected data (RAI 34).

SRS Response: The response to U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) Comment 34 (WSRC 2005) indicated that the relative permeability measurement for a saltstone sample is "not regarded as reliable" in retrospect, due to an abrupt and anomalously high increase in gas flow during the laboratory test (WSRC 2005; p. 223-226). Further re-examination of the laboratory testing and data analysis for saltstone and vault concrete indicates it cannot be used as the basis for the moisture curves used in numerical modeling of these materials. Thus, we acknowledge uncertainty in the moisture curves assumed for saltstone and concrete.

The effect of potentially higher relative permeability on dose was assessed from the results of sensitivity case 13 described in the response to NRC RAI Comment 19 (WSRC 2005; p. 133-155). This case used the saturated conductivity value even under unsaturated conditions. Specifically, the scenario assumes that the relative permeability of saltstone and concrete is 1.0 regardless of saturation/suction head. The result is a relatively minor increase in dose from 0.05 mrem/yr to 0.19 mrem/yr. For reference, the performance objective for the facility is a dose not exceeding 25 mrem/yr.

This sensitivity case demonstrated that the uncertainty in the moisture curve assumption does not impact the validity of the numerical modeling results.

References:

WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision. 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 16 (7/27/05): ***Vault Saturation Sensitivity Data***

Provide sensitivity analysis and/or model support for saturation of the vaults (RAI 35).

SRS Response: Additional sensitivity analysis related to saturation of the vaults is provided in the response to U. S. Nuclear Regulatory Commission (NRC) Action Item 10 (8/17/05) contained within this document. The sensitivity cases associated with saturation of the vaults are sensitivity cases 31 and 32.

In scenario 31, the vault and Saltstone were assumed to exhibit large-scale cracking at a 30-foot nominal spacing. The cracks were assumed to be fully saturated by redefining the water retention and relative permeability curves, such that both are 1.0 regardless of the suction head. An additional radionuclide, Np-237, was included in the scenario.

Scenario 32 is the same as scenario 31, except that it is assumed that the vault and Saltstone have no reducing capacity (i.e., oxidizing K_d is used for Tc-99). This scenario assumes complete loss of reducing capacity of the vault and Saltstone at time zero.

A detailed discussion of the results from these sensitivity cases is included in the response to NRC Action Item 10 (8/17/05).

Action Item 17 (7/27/05): ***Process Controls for Controlling/Evaluating Grout Composition***

Provide description of the process controls in place for controlling/evaluating grout composition for broad range of waste streams sent to Saltstone Production Facility (RAI 38).

SRS Response: As discussed in the Savannah River Site (SRS) response to the U. S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) Comment 38 (WSRC 2005), there are numerous variables that affect the processibility and functionality of the grout. However, operating history at the Saltstone Facility has shown that, as long as certain physical and chemical properties of the waste are maintained within specified bounds, the premix-to-water ratio can be varied between 0.60 and 0.66 to produce a grout that has acceptable characteristics. These physical and chemical properties include organic content of the waste, salt content of the waste (as indicated by sodium ion concentration), temperature, pH, and amount of insoluble solids in the waste. Also, the concentration of hazardous materials in the waste must be limited to within the capacity of the current grout formulation.

The primary control in place to verify the processibility of the waste and the acceptability of the final waste form is the Saltstone Facility Waste Acceptance Criteria (WAC) (WSRC 2004). The Saltstone WAC document is implemented via a series of waste samples, grout quality studies and grout formulation studies. In accordance with the Tank 50 sample strategy (Ketusky 2005), a material balance will be maintained on Tank 50 to track the chemical and radiological properties of the tank contents as waste is transferred into and out of the tank.

In order to transfer waste from Tank 50 to the Saltstone Facility for treatment, the chemical and radiological properties of the aggregate waste in Tank 50, as indicated by the material balance, must meet the specific criterion stated in the Saltstone WAC. Thus, the physical and chemical properties of the waste that have a major impact on the processibility of the waste and the acceptability of the final waste form are verified to be within acceptable values prior to waste processing.

The Saltstone WAC directs that Tank 50 be sampled to verify that the material balance is accurately tracking the physical, chemical and radiological properties of the waste. The Saltstone WAC also directs the waste generator to sample the waste and verify that it meets specific physical, chemical, and radiological criterion every time a new batch of salt solution from DDA activities is ready for treatment. This is required because the volume of the salt batches from DDA activities is large enough to cause a significant shift in the physical, chemical, and radiological properties of the waste in Tank 50. If there are significant changes in the physical and chemical properties of the waste, a grout formulation study will be performed to verify the proper premix-to-water ratio for that batch of salt solution. In addition, every three months, grout made from waste and premix (using the current premix-to-water ratio) will undergo Toxicity Characteristic Leaching Procedure (TCLP) testing to verify that the grout remains non-hazardous.

References:

Ketusky, E. T., 2005, *Sampling Strategy for Tank 50 Point of Compliance Samples to Saltstone,* CBU-PIT-2005-00014, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2004, *Waste Acceptance Criteria for Aqueous Waste sent to the Z-Area Saltstone Production Facility*, X-SD-Z-00001, Revision 2, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 18 (7/27/05): ***Concentration Fluxes of NO_3 in the Vault Area***

Provide information regarding concentration fluxes of NO_3 in the vault area (RAI 45, 46).

SRS Response: In discussions during the public meeting between the U. S. Nuclear Regulatory Commission and the U. S. Department of Energy on July 27, 2005, two questions were raised regarding this topic. The first question requested information to define the fraction of the water reaching the vault that traveled through the vault versus the fraction that flowed around the vault. Figure 18-1 below plots the fraction of the infiltration reaching the vault that enters the vault system for the base case in the 2005 Special Analysis (Cook et al. 2005). The fraction ranges from about 1E-6 at 100 years to about 2E-4 at 10,000 years. The remaining water flows around the vault.

The second question requested comparison of the concentration of nitrate in the vadose zone to the concentration at the 100 m well. Figure 18-2 below shows the ratio of the concentration of I-129 in the vadose zone (averaged over the row of cells immediately above the water table) to the concentration of I-129 at the 100 meter well. This information was extracted from the detailed PORFLOW output files for the base case presented in the 2005 Special Analysis (Cook et al. 2005). Nitrate and I-129 will behave very much the same because both have very low K_ds and I-129 has a very long half life. The ratio changes with time because as the infiltration increases a greater mass of contaminant is injected into the groundwater system.

Figure 18-1:

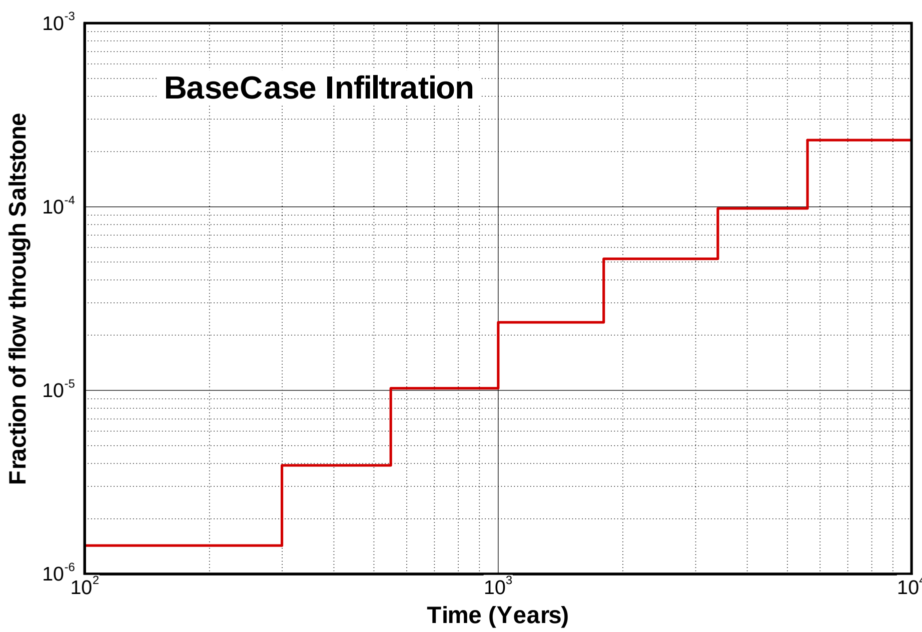
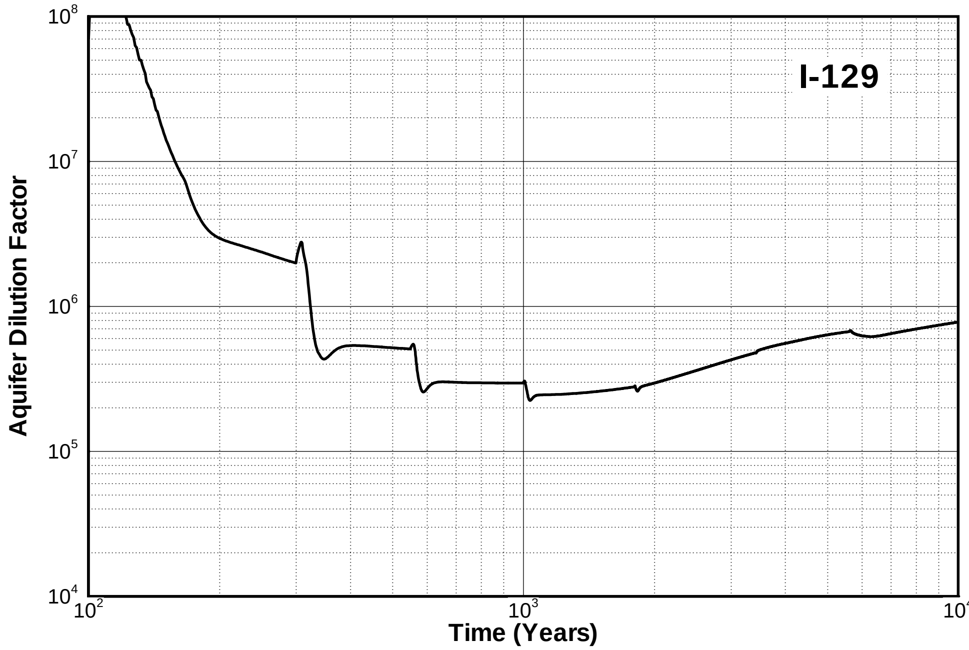


Figure 18-2. Ratio of I-129 concentration in vadose zone to I-129 concentration at 100 meter well.



References: Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 19 (7/27/05): ***Data for Soil-to-Plant Transfer Factors***

Provide information regarding the use of generic data for soil-to-plant transfer factors rather than site-specific information, or the sensitivity to the use of that data (RAI 56).

SRS Response: *Site Specific Information*

It is not clear that the site-specific data presented in Murphy 1990 (NRC 2005, Reference 24) can be directly interpreted as a soil-to-plant transfer factor. The measurements presented are for vegetation grown on top of a lysimeter containing Saltstone and sump water collected at the bottom of the lysimeter. Table 6 from Murphy 1990 (attached to this response) presents the ratios of these results for Tc-99 in units of pCi/g of plant material per pCi/L of sump water (customary units for water concentration, C_{water}, are pCi/mL). There is no reason to assume that the soil in which the vegetation was grown was in equilibrium with the water in the sump; however, if that is assumed to be the case, then to convert the given results to the conventional units for soil-to plant uptake factor, the sump water concentration, $C_{sump\ water}$, must be converted to a soil concentration, C_{soil}, using the K_d relationship:

$K_d = C_{soil} / C_{water}$

with units of pCi/g / pCi/mL

to give K_d in the customary units of mL/g.

This can be rearranged as:

$C_{soil} = C_{water} \text{ x } K_d$

The 2005 Special Analysis (Cook et al. 2005) uses a K_d of 0.1 mL/g for Tc, so:

$C_{soil} = 0.1 \text{ x } C_{water}$

To account for the lysimeter sump water data being in units of pCi/L a conversion factor of 1E-3 L/mL needs to be applied, so that:

$C_{soil} = 1E\text{-}4 \text{ x } C_{sump\ water}$

Making the conversion, the Vegetation Type and Mean ratios in Murphy 1990, Table 6, can be presented as soil-to-plant uptake factors by multiplying by 1E-4. The resulting values are shown in Table 19-1:

Table 19-1. Mean Soil-to-Plant Transfer Factors.

Vegetation Type	Mean Soil-to-Plant Transfer Factor pCi/g / pCi/g
Grass	
1987	4.68E-5 (1.67E-5)
1988	6.77E-5 (3.49E-5)
Trees	
1986	1.11E-5
1987	3.23E-5
Crops	
Corn Stalk	1.164E-4 (3.71E-5)
Wheat Straw	1.83E-5
Corn Kernel	7.03E-9
Wheat Kernel	8.20E-9
Note: Numbers in parenthesis are the values of the mean with a single exceptionally high value removed (see Figures 20 and 22 of Murphy 1990)	

Since these values are far smaller than any found in the cited literature, it is concluded that this data is not suitable for calculating site-specific soil-to-plant transfer factors.

Sensitivity of Results to ^{99}Tc Plant to Soil Uptake Factor

The assumption was made in the 2005 Special Analysis (SA) that all of an inadvertent intruder's vegetative consumption was of reproductive parts (seed and roots) and that no leafy parts were eaten. Using the soil-to-plant transfer factor for vegetative functions, $B_{v,}$ and reproductive or storage functions, $B_{r,}$ values for Tc from Baes et al. 1984 of 9.5 and 1.5 respectively, and assuming that 10% of the intruder's consumption was of leafy parts, then the weighted average factor would be:

(0.1 x 9.5) + (0.9 x 1.5) = 2.30

Converting this to a dry weight basis to be consistent with the 2005 SA gives:

2.30 x 0.43 = 0.989

Compared to the values used in the 2005 SA of 0.645,

0.989 / 0.645 = 1.53

under these conditions, the plant consumption portion of the Tc-99 intruder dose would increase by about 50%.

The value of 0.989 was input into the intruder sensitivity analysis for Resident, Post Drilling and Agricultural scenarios. The differences are shown in Table 19-2 below in terms of the calculated Tc-99 inventory limit for each scenario.

Table 19-2. Calculated Tc-99 Inventory limits

Tc-99 Disposal; Limits			
Scenario	2005 SA Result, Ci	10% Leafy in Diet, Ci	Ratio
Resident	3.66E+13	3.66E+13	1
Post Drilling	6.53E+03	4.26E+03	1.53
Agriculture	1.09E+03	7.14E+02	1.53

Thus, the Tc-99 results for intruder scenarios which involve consumption are sensitive to the make-up of the diet assumed in the analysis. In the 2005 SA, those scenarios were included as sensitivity studies and the results did not affect the calculated disposal limits.

Table 6. Mean Ratios of Tc-99 Activity in Vegetation versus Lysimeter Sump Water for Different Vegetation Types in Units of (pCi/gm)/(pCi/L).

Vegetation Type	Mean	Standard Deviation	Number of Lysimeters
Grass			
1987	0.468 (0.167)	0.906 (0.094)	9
1988	0.677 (0.349)	1.071 (0.280)	10
Trees			
1986	0.111	0.078	4
1987	0.323	0.219	3
Crops (all 1987)			
Corn Stalk	1.164 (0.371)	1.789 (0.280)	5
Wheat Straw	0.183	0.107	5
Corn Kernel	0.000703	0.000557	4
Wheat Kernel	0.000820	0.000443	5

Note: Numbers in parenthesis are the values of the same statistic with a single exceptionally high value removed (see Figures 20 and 22).

Murphy 1990

References: Baes III, C. F., Sharp, R. D., Sjoreen, A. L. and Shor, R. W., 1984, *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture*, ORNL-5786, Oak Ridge National Laboratory.

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Murphy, C. E., Jr., 1990, *Lysimeter Study of Vegetative Uptake from Saltstone*, WSRC-RP-90-421, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC, 2005, *Request for Additional Information on The Draft 3116 Determination for Salt Waste Disposal at the Savannah River Site*, Scott C. Flanders to Mark A. Gilbertson, May 26, 2005.

Action Item 20 (7/27/05): ***Sheet Drain Cure/Bleed Water and Sulfate Degradation***

Provide information regarding the sheet drain and cure/bleed water, as well as sulfate degradation assumptions (RAI 39).

SRS Response: Information pertaining to the sheet drain and cure/bleed water was provided as a presentation entitled *Saltstone Vaults* (Thompson 2005) at the public meeting between the U. S. Nuclear Regulatory Commission and the U. S. Department of Energy on August 17-18, 2005 held in North Augusta, South Carolina. A copy of the presentation slides is included with this submittal.

In order to limit the hydrostatic pressure applied to the base of the vertical cell walls, various cells in Vault 4 were backfitted with a Leachate Collection System. In the past, excess bleed water, combined with rainwater from inleakage and condensate from the humid atmosphere, provided sufficient hydrostatic pressure on the bottom of the cell walls to cause the vault walls to crack. Drain holes had to be drilled through the vault walls to relieve the pressure and the cracks in the vault walls had to be repaired.

As part of a facility modification, sheet drains were installed on the interior surfaces of the vertical walls of cells D, E, F, J, K, and L in Vault 4. The sheet drains consist of a 7/16-inch thick polystyrene, egg-carton shaped drain core covered on one side with polypropylene filter fabric. The filter fabric allows the excess water to pass into the drain core while restricting the movement of the unset grout. The water that passes through the fabric is then free to fall by gravity to the bottom of the sheet drain. A 12-inch diameter drain pipe was installed along the entire interior circumference of each of the associated cells to contain the water received in the sheet drains. The bottom of the sheet drain is connected to the drain pipe at ports installed approximately every five feet along the pipe's circumference. Each cell's drain pipe has the capacity to store approximately 2350 gallons of excess bleed water, rainwater, and condensate, which is collectively referred to as leachate.

The collected leachate is periodically removed from the individual cells via the Leachate Removal System. A separate two-inch diameter collection header is installed along both the east and west sides of Vault 4. A two-inch wall penetration and associated isolation valve connect the 12-inch drain pipe in each cell with its associated collection header. Two leachate pumps, one on each side of Vault 4, are installed to transfer the leachate via a common return line to the Saltstone Feed Tank (SFT) so that the leachate can be processed into grout during the next production run. The leachate return line consists of approximately 1300 feet of one-inch and 450 feet of three-inch stainless steel transfer line. The three-inch line has a six-inch carbon steel jacket, which drains to the SFT dike. The leachate return line is sloped from a high-point located on top of Vault 4 such that when the leachate return pumps are stopped, the remaining leachate in the line drains by gravity either to the SFT or back to the leachate pump. The leachate pump can be operated in reverse to pump liquid back to the cell. The two-inch wall penetration that connects the 12-inch drain pipe in each cell with its associated collection header will be cut, filled with non-shrinking grout, and capped during vault closure activities, prior to backfilling with soil around the vault. Prior to final closure activities, the effects of the vault wall penetrations on the long-term performance of the vault will be evaluated. If it is determined that the vault wall penetrations cause unacceptable vault performance, the penetrations will be removed and the openings patched using standard industrial practices for concrete repair or using an alternate method that achieves appropriate performance objectives. The requirement to evaluate the effects of the vault wall penetrations on the long-term performance of the vault will be documented in the Closure Plan for the Z-Area Saltstone Disposal Facility.

The sheet drain protects the vault concrete from sulfate containing bleed water from the Saltstone. In addition to the polystyrene liner/sheet drain, the response to NRC RAI 39 (WSRC 2005) further details how the vault is resistant to sulfate attack because of its low tri-calcium aluminate (C3A) content and low porosity mix design.

References:

Thompson, D., 2005, *Saltstone Vaults*, PIT-MISC-0087, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision 1, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 21 (7/27/05)*: Characterization and Design for Existing Vaults*

Provide information on the characterization and design for the existing vaults at the saltstone facility and the already-emplaced saltstone (RAI 42).

SRS Response: Grout is pumped through a transfer line from the Saltstone Processing Facility to the vault roof. Piping and valving on the vault roof are aligned to direct the grout pour to the center of the roof of the cell to be filled. Based on visual observation by Saltstone Operations personnel, the grout has the appearance of latex paint as it is poured into the cell. As the grout flows toward the sides of the vault it begins to gel, taking on the appearance of flowing lava. The flow is self-leveling. No large gaps or fissures have been observed on the grout surface. However, due to shrinkage of the grout during hydration, small gaps occur between the solidified grout and the vault walls/sheet drains, allowing excess bleed water and condensation to flow in this void. This excess bleed water and condensate are collected and subsequently removed by the Leachate Collection and Return Systems. During subsequent grout pours, these small gaps are filled as the poured grout flows across the surface toward the walls/sheet drains.

After a cell is filled to the 25-foot level and ready for closure, the remaining space up to the vault roof will be filled with clean grout. The design of the vault includes 50 three-inch pipes which penetrate the roof of each cell. These pipes provide capped ports for pouring clean grout into the cell. The pipes are evenly spaced across the roof, allowing complete coverage of the cell. Each pipe will be filled with grout and capped when the cell is closed. Prior to final closure activities, the effects of the roof penetrations on the long-term performance of the vault will be evaluated. If it is determined that the roof penetrations cause unacceptable vault performance, the penetrations will be removed and the openings patched using standard industrial practices for concrete repair or using an alternate method that achieves appropriate performance objectives. The requirement to evaluate the effects of the vault roof penetrations on the long-term performance of the vault will be documented in the Closure Plan for the Z-Area Saltstone Disposal Facility.

Historically, grout samples were taken at the Saltstone Facility to demonstrate compliance with regulatory requirements and to provide confirmation of consistency of the physical properties of the emplaced material with those properties observed during grout formulation testing. These samples were obtained from the discharge of the mixer. Once during every month that the facility operated, a grout sample was sent to an independent laboratory to verify the non-hazardous classification of the grout using the Toxicity Characteristic Leaching Procedure (TCLP). This sample is required because the Saltstone vaults are permitted by the State of South Carolina as a non-hazardous landfill. All grout currently emplaced in the Saltstone vaults is classified as non-hazardous.

The majority of the grout samples taken in the facility were confirmatory in nature. These grout samples were used to verify that the physical properties of the grout such as set time, gel time, bleed water, and compressive strength, were consistent with those values seen during the grout formulation testing. The results of all the confirmatory samples taken during previous operations of the Saltstone Facility were consistent with the results of the grout formulation testing. Due to the consistency of these confirmatory results and in an effort to maintain radiation exposure doses to the workers as low as reasonably achievable (ALARA), future confirmatory samples are not currently planned. Information regarding future sampling plans is provided in the response to NRC Action Item 11 (7/27/05).

Action Item 22 (7/27/05): ***Explanation of Values used for Sum of Fractions***

Provide correction or explanation of inconsistent values used for sums of fractions on Page 94 of the PODD.

SRS Response: The sensitivity information found on page 94 (and other cases in Section 8) of *Saltstone Performance Objective Demonstration Document* (PODD) (Rosenberger et al. 2005) is taken directly from Saltstone Special Analysis (SA) (Cook et al. 2005). The SA presents information only for Saltstone Vault 4 and the sensitivities therefore represent only the Saltstone Vault 4 inventory and results. The SA results allow an evaluation of the sensitivity of the results to modeling changes. The PODD sum of fractions presented in Section 4.3.2 for the all-pathways scenario represents a value for the entire present and projected future salt waste inventory of the Saltstone Disposal Facility all located in a single vault for evaluation against performance objectives. Because the inventories are for either Saltstone Vault 4 only (Section 8) or the entire projected inventory (Section 4.3.2) the sum of fractions will not be similar between Section 4.3.2 and the sensitivity cases presented in Section 8 of the PODD.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Rosenberger, K. H., Rogers, B. C. and Cauthen, R. K., 2005, *Saltstone Performance Objective Demonstration Document*, CBU-PIT-2005-00146, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 1 (8/17/05): ***Colloidal Transport***

Provide information supporting the neglect of colloidal transport in DOE's modeling (RAIs 48, 58).

SRS Response: Subsurface mobile colloids are particles that are less than 1 micron in size that move with the aqueous phase. The results of two specific colloid studies conducted at the Savannah River Site (SRS) were used to support the colloidal transport assumptions in the DOE's modeling. The first study, Kaplan et al. (1994), measured plutonium (Pu) associated with a filterable fraction in groundwater recovered in F-Area. F-Area is nearby and in the same geological formation as Z-Area, the area in which the Saltstone Disposal Facility is located. From this study, very little Pu (fentocurie level, i.e., 1E-15 Ci/L) was found in association with colloids (Kaplan et al. 1994, Table 2). The percentage of Pu retained by filters, presumably colloidal, increased as the pH of the plume increased, which was also coincidental with distance from the point source (Table 1-1 below). Inversely, the percentage of Pu that passed through the smallest membrane, 500 MW (~0.5 nm) decreased with distance from the point source (Table 1-1). The ratio between the Pu concentration of colloids in well water and liquid in the source zone did not change in a systematic manner with distance (or pH) in the field (Table 1-2 below).

The second study, Dai et al. (2002) from Woods Hole Oceanographic Institution also conducted a colloid study in F-Area and concluded that colloids were not involved in Pu transport. The difference between these two results, (i.e., Kaplan et al. (1994) reporting little colloidal Pu and Dai et al. (2002) reporting essentially no colloidal Pu) may be attributed to the latter sampling, some 8 years later, in a somewhat more basic plume, and to differences in experimental technique. Dai et al. (2002) used more sensitive analytical methods but larger molecular weight cut-off membranes (permitted larger particles to pass through (1000 MW (~1 nm))) than those used by Kaplan et al. (1994).

A ranking of radionuclides in order of their tendency to associate with F-Area colloids is: Pu > Th > U > Am = Cm > Ra > tritium (Kaplan et al. 1994).[6] The stronger the tendency of a radionuclide to associate with colloids, the greater the tendency for them to be transported by colloids. Not surprisingly, tritium was found not to be associated with colloids; this is because it does not bind to mineral surfaces. Since Pu has the highest tendency to associate with F-Area colloids, the studies of colloidal transport of Pu can be used to bound the other radionuclides.

[6] It should be noted that Th and U in this study included anthropogenic and natural sources, compromising interpretation of the data. A vast majority of the Th and U in this system were of natural sources.

The F-Area studies can be used to support modeling assumptions for colloidal transport in Z-Area because F-Area is located in geographical proximity to Z-Area and because both areas are in the same geological formation. An important difference between the F-Area plume and that expected from the Saltstone Z-Area is that the former is acidic, ranging from pH 3.4 to 4.8 (Table 2; Kaplan et al. 1994), and the latter plume is expected to be alkaline, pH >10 at Saltstone to 5.5 at background. The implications of this difference are that most radionuclides would tend to sorb (adsorb/precipitate/coprecipitate) more readily in the Z-Area system. In an environment that may have a more similar pH than that of F-Area (i.e., the Hanford Site), Dai et al. (2005) reported that "There is no clear evidence for colloid facilitated transport of Pu in groundwater at the Hanford Site, since downstream wells have both an order of magnitude lower concentrations of Pu and a lower fractional colloidal distribution."

In summary, there is field evidence that colloids facilitate little or no Pu transport in the field site in which they were studied, F-Area, which is nearby and in the same geological formation as Z-Area. There are no field studies on the SRS or elsewhere demonstrating release of colloidal Pu or other radionuclides from cementitious environments.

Table 1-1. Nuclide size fractionation (%) in groundwater samples collected in F-Area (Kaplan *et al*. 1994; Table 4; Well I, II, and III are 30, 320 and 550 m from the Pu point source and have a pH of 3.4, 3.6, 4.0, respectively)

Well	Nuclide	>0.4 µm	0.4 µm–3000 MW*	3000 MW–500 MW	<500 MW
I	Pu	0	9	19	72
	Th	2	9	13	76
	Am	0	0	45	55
	Cm	0	0	42	58
	Ra	0	17	18	64
	U	0	24	31	45
	^{3}H	0	0	0	100
II	Pu	3	0	59	38
	Th	10	14	15	62
	Am	0	0	56	44
	Cm	0	0	59	41
	Ra	0	21	0	79
	U	0	3	47	50
	^{3}H	0	0	0	100
III	Pu	0	0	100	0
	Th	0	100	0	0
	Am	0	0	0	100
	Cm	0	0	0	100
	Ra	0	0	0	100
	U	0	0	52	48
	^{3}H	0	0	3	97

* MW = nominal molecular weight cutoff value of membrane.

Table 1-2. Actinide activity in groundwater (A_{well}) normalized to activity in seepage basin water (A_{waste}) (Kaplan *et al*. 1994; Table 3)

Nuclide	$A_{wellX}/A_{waste} \times 100$				
	Waste activity[a] ($pCi\ l^{-1}$)	Well I (%)	Well II (%)	Well III (%)	Background Well (%)
^{239}Pu	308	0.0029	0.0045	0.0011	<0.0002
^{241}Am	308	7.14	24.35	2.27	0.13
$^{243,244}Cm$	154	10.32	68.18	7.14	0.46
^{238}U	2,080	8.56	38.37	8.37	0.72
^{3}H	26,700,000[b]	21.69	16.03	3.41	0.034

[a] Means of 9 samples collected between September and December 1983 [13].
[b] Activity corrected for decay.

References: Dai, M., Kelley, J. M. and Buesseler, K. O., 2002, *Sources and Migration of Plutonium in Groundwater at the Savannah River Site*, Environ. Sci. Technol. 36:3690–3699.

Dai, M., Buesseler, K. O. and Pike, S. M., 2005, *Plutonium in Groundwater at the 100K-area of the U.S. DOE Hanford Site. J.,* Contam. Hydrol. 76:167–189.

Kaplan, D. I., 2004, *Recommended Geochemical Input Values for the Special Analyses of the Slit/Engineered Trenches and Intermediate Level Vault,* WSRC-RP-2004-00267, Westinghouse Savannah River Company, Aiken, South Carolina.

Kaplan, D. I., Bertsch, P. M., Adriano, D. C. and Orlandini, K. A., 1994, Actinide *Association with Groundwater Colloids in a Coastal Plain Aquifer*, Radiochimica Acta 66/67:181–187.

Action Item 2 (8/17/05): ***Release Models based on Solubility***

Provide information supporting the use of release models based on solubility rather than K_d's (RAI 60).

SRS Response: Plutonium and uranium chemistry in reducing and non-reducing saltstone will be controlled by a number of chemical processes, including complexation, hydrolysis, precipitation, adsorption, coprecipitation, and redox. Very little data is currently available on these chemical processes. Therefore, rather than attempt to identify and then quantify these chemical processes involved in immobilizing Pu and U in saltstone, an empirical approach of using conservative literature data was taken. This data, without exception, does not elucidate the removal mechanism, but does provide a simple "total sorption" value, or K_d value. As such, the K_d value provides a measure of all the sorption processes including precipitation and coprecipitation (as quantified by the solubility constant). Thus, if removal processes, in addition to precipitation are occurring in the saltstone, then the empirical K_d values would be expected to measure more removal than expected based simply on solubility considerations.

The Pu and U K_d values used in the 2005 Special Analysis (SA) (Cook et al. 2005) were taken from Bradbury and Sarott (1995), who provided a compendium of conservative K_d values for cementitious environments based on measured experiments. DOE's selection of input values was based on this critical review of conservative K_d values because it was consistent, well documented, and well reasoned.

The Appendix to this response includes a comparison of the aqueous concentrations calculated based on the K_d values used in 2005 SA and based on solubility calculations. The results show that the K_d values estimated lower (less conservative) Pu and U aqueous concentrations than the solubility calculations. However, the measured K_d values which served as the basis of the values presented in Bradbury and Sarott (1995) include the effects of all of the chemical processes discussed above rather than merely the effects of solubility. Therefore, this comparison is not an indication that greater conservatism is required in the 2005 SA calculations. Instead, SRNL believes that, in addition to precipitation/coprecipitation, adsorption is an important process controlling aqueous U and Pu concentrations (EPA 1999; for Pu Sections 5.6.4 & 5.6.5 and for U Sections 5.11.4 & 5.11.5).

Appendix

Brady and Kozak (1995) calculated the solubility limits of Pu and U in a Low Level Waste cementitious environment. They assumed that $PuO_2(OH)_2$ controlled the solubility of aqueous Pu and that Haiweeite ($Ca(UO_2)_2Si_6O_{15}$-$5H_2O$) controlled the solubility of aqueous U. They are reproduced in Table 2-1 below. The Pu and U concentrations in the "Oxygenated" cementitious environment and "Non-Oxygen, no CO_2 exchange" environment were compared to those that the 1992 PA's K_d values would predict. To do this, the K_d equation was used:

(1) $$K_d = C_{solid}/C_{liquid}$$

where, C_{solid} and C_{liquid} is the concentration of the radionuclide in the solid and liquid, respectively. Equation (1) was rearranged as:

(2) $$C_{liquid} = C_{solid}/K_d$$

C_{liquid} was then compared to the solubility concentrations for Pu and U in Table 2-1. If C_{liquid} was greater than the solubility concentration, then it suggested that the use of the K_d construct was conservative with respect to the solubility construct.

Calculations showing this comparison are presented in Table 2-2. C_{solid} is presented in Column F and C_{liquid} is presented in Column K of Table 2-2. Columns L and M show that all the Pu and U concentrations calculated based on K_d values were always several orders of magnitude lower than those based on solubility limits. If solubility was the only controlling process, then this would indicate that the K_d values used in the 2005 SA were not conservative. More likely, these calculations indicate that processes other than precipitation/coprecipitation are controlling aqueous Pu and U concentrations.

Finally, the 2005 Special Analysis and all the sensitivity runs (see response to NRC Action Item 10 (8/17/05)) show that the contribution of both U and Pu to the all pathways dose are insignificant (orders and orders of magnitude below 25 mrem/yr).

Table 2-1. Solubility concentrations of selected radionuclides in three cementitious environments based on thermodynamic calculations (Brady and Kozak 1995 (Table 3); DBLC = dose-base limiting concentrations; this is a non-regulatory limit and is not related to this discussion).

Concentration (mol/l)				
Element	Oxygenated	Non-Oxygen. no CO_2 exchange	Non-Oxygen. p CO_2 $10^{-1.5}$ atm	${}^a[i]_{DBLC}$
Pu	1.7E–7	1.3E–10	1.5E-6	1.1E–15
Am	1.1E–9	4.0E–9	1.5E–8	6.3E–16
Th	3.4E–7	3.4E–7	3.5E–7	2.0E–8
Ni	4.4E–4	7.6E–13	1.4E–16	1.7E–11
Ra	3.0E–7	*	*	6.2E–15
Sr	2.1E–5	2.1E–5	4.0E–5	2.4E–13
U	1.2E–8	2.1E–9	1.7E–13	5.7E–12
Tc	*	1.6E–38	3.6E–22	1.4E–8
Cs	*	*	*	5.9E–14
I	*	*	*	1.7E–10
C	6.1E–4	1.5E–3	7.7E–3	1.9E–6

*Solubility > 10^{-3}M.

Table 2-2. Comparison of aqueous concentrations in saltstone based on solubility limits versus Kd values.

Column	B	C	D	E	F	G	H	I	J	K	L	M
Element	Isotope (Atomic Mass)	Saltstone, (Ci/m^3)	Specific Activity Conversion Factors (g/Ci)	Saltstone, Col_C*Col_D (g/m^3)	Saltstone, C_{solid} in Eq. 2 (mol/g)	QA check of calculation in Col F	Reducing Condition Solubility Limit (mol/L)	Oxidizing Conditions Solubility Limit (mol/L)	Kd 1992 PA (mL/g)	Aqueous Conc. Based on Kd, C_{liquid} in Eq. 2 (mol/L)	Is Kd Conservative w.r.t.reducing solubility limit? (Is Col K > Col H?)	Is Kd Conservative w.r.t. oxidizing solubility limit? (Is Col K > Col I?)
Pu	238	4.30E-05	5.84E-02	2.51E-06	6.21E-15	6.21E-15	1.30E-10	1.70E-07	5000	1.24E-15	No	No
Pu	241	2.80E-05	9.67E-03	2.71E-07	6.61E-16	6.61E-16	1.30E-10	1.70E-07	5000	1.32E-16	No	No
Pu	239	1.10E-06	1.61E+01	1.77E-05	4.36E-14	4.36E-14	1.30E-10	1.70E-07	5000	8.72E-15	No	No
Pu	240	2.80E-07	4.41E+00	1.23E-06	3.02E-15	3.02E-15	1.30E-10	1.70E-07	5000	6.05E-16	No	No
U	234	2.30E-07	1.61E+02	3.70E-05	9.29E-14	9.29E-14	2.10E-09	1.20E-08	2000	4.65E-14	No	No
U	232	3.90E-08	4.47E-02	1.74E-09	4.42E-18	4.42E-18	2.10E-09	1.20E-08	2000	2.21E-18	No	No
U	233	2.30E-09	1.04E+02	2.39E-07	6.02E-16	6.02E-16	2.10E-09	1.20E-08	2000	3.01E-16	No	No
U	238	1.70E-09	2.98E+06	5.06E-03	1.25E-11	1.25E-11	2.10E-09	1.20E-08	2000	6.25E-12	No	No
	Comments	a	b		c	OK	d	e	f	g	h	i

Comments

a	Page 2-66; Table 2.6-2 in MMES (1992).
b	g/Ci = (A*$T_{1/2}$)/1.128E-13); A = Atomic Mass (Column B), $T_{1/2}$ = half life (seconds)
c	Conversion for "saltstone g/m^3" to "saltstone mol/g": (g/m$^-$) x (1mol/238g) x (1m^3/1.7e3 kg) x (1 kg/1000g); bulk density value, 1.7e3 kg/m^3, from page 2-56 in MMES (1992).
d	Reducing conditions values from Brady and Kozak (1995), page 196, Table 3. See table below.
	$Pu(OH)_4$ controls solubility; U solubility is controlled in reducing environment by $U(OH)_4$: uraninite.
e	Oxidizing values also from same table in Brady and Kozak (1995); Hydrated solid $Pu_2(OH)_2$ controls Pu solubility.
	U solubility is controlled by Haiweeite, a calcium-uranium-silicate hydroxide, observed to form at low temperatures.
f	Pu Kd value from Table A.1-2 in MMES 1992. U Kd value from Bradbury and Sarott 1995.
h	If Col K is less than Col H than Kd approach is conservative with respect to (w.r.t.) the reducing condition solubility limit.
i	If Col K is less than Col I than Kd approach is conservative with respect to (w.r.t.) the reducing condition solubility limit.

References:

Bradbury, M. H. and Sarott, F., 1995, *Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment*, Nr. 95-06, Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Brady, P. V. and Kozak, M. W., 1995, *Geochemical Engineering of Low Level Radioactive Waste in Cementitious Environments*, Waste Management 15(4):293–301.

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

MMES, 1992, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Westinghouse Savannah River Company, Aiken, South Carolina.

EPA (Krupka, K. M., D. I. Kaplan, G. Whelan, R. J. Serne, and S. V. Mattigod), 1999, *Understanding Variation in Partition Coefficient, Kd, Values. Volume II: Review of Geochemistry and Available Kd Values, for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium*, EPA 402-R-99-004A, Office of Air and Radiation, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, DC. (http://www.epa.gov/radiation/cleanup/partition.htm)

Action Item 3 (8/17/05): ***Closure Cap Design Details***

Provide additional information, such as design details, supporting assumptions that the cap will not fail due to erosion in less than 10,000 years (RAIs 22, 25).

SRS Response: Final closure of the Saltstone Disposal Facility (SDF) is primarily intended to physically stabilize the site, minimize infiltration, and provide an intruder deterrent. Final closure will consist of site preparation and construction of an integrated closure system composed of one or more closure caps installed over all the vaults and a drainage system. Since the SDF is currently in the initial phase of its 30-year operation period, contains only two existing vaults, and will require an unspecified number of additional vaults on a yet to be determined layout, the information provided herein on the closure cap is appropriately a scoping level concept. It provides sufficient information for planning purposes and to evaluate the closure cap configuration relative to its constructability and functionality, but it is not intended to constitute final design. Appendix A of this response provides the scoping level calculations and/or estimations that have been made in order to ensure that, relative to erosion, the closure cap will remain physically stable for 10,000 years. The information provided herein will be included within the next revision of the SDF closure plan to ensure that the information will be included as input to the final design of the SDF closure cap.

Background

The SDF or Z-Area is a rectangular shaped area comprising approximately 160 acres. It is located on a local topographic high with surface elevations generally ranging from 260 to 300 ft-msl with the corner closest to McQueen Branch (i.e., eastern corner) dipping to 240 ft-msl (see Figure 3-1). The historic high groundwater beneath SDF is approximately thirty feet deep at the northern corner, twelve feet deep at the eastern corner, forty-six feet deep at the southern corner, and twenty-seven feet deep at the western corner (Hiergesell 2005). The nearest stream, McQueen Branch, drains an area of approximately 4.3 square miles and is at an elevation of approximately 190 ft-msl. Z-Area ranges from 50 to 110 feet above McQueen Branch and is well out of the flood plain of any nearby stream. The SDF is not subject to flooding from nearby streams but could be subject to extreme precipitation events (WSRC 1992).

Vaults #1 and #4 currently exist in the SDF. The vault locations are shown on Figure 3-1, and Figure 3-2 provides an aerial view of the vaults. Vault #1 is approximately 600 feet long by 100 feet wide by 25 feet high with six 100-foot by 100-foot cells. Vault #4 is approximately 600 feet long by 200 feet wide by 27 feet high with twelve 100-foot by 100-foot cells. Vaults #1 and #4 were built approximately 10 to 15 feet below original grade and the soil was stockpiled for later use. An unspecified number of additional vaults, on a yet to be determined layout, will be required. It is anticipated that active Saltstone disposal operations will last for approximately 30 years. Installation of a closure cap over all of the vaults is not anticipated until the end of the 30-year operational period. A minimum 100-year institutional control period will follow installation of the closure cap (WSRC 1992).

Figure 3-1. Saltstone Disposal Facility (SDF) Location

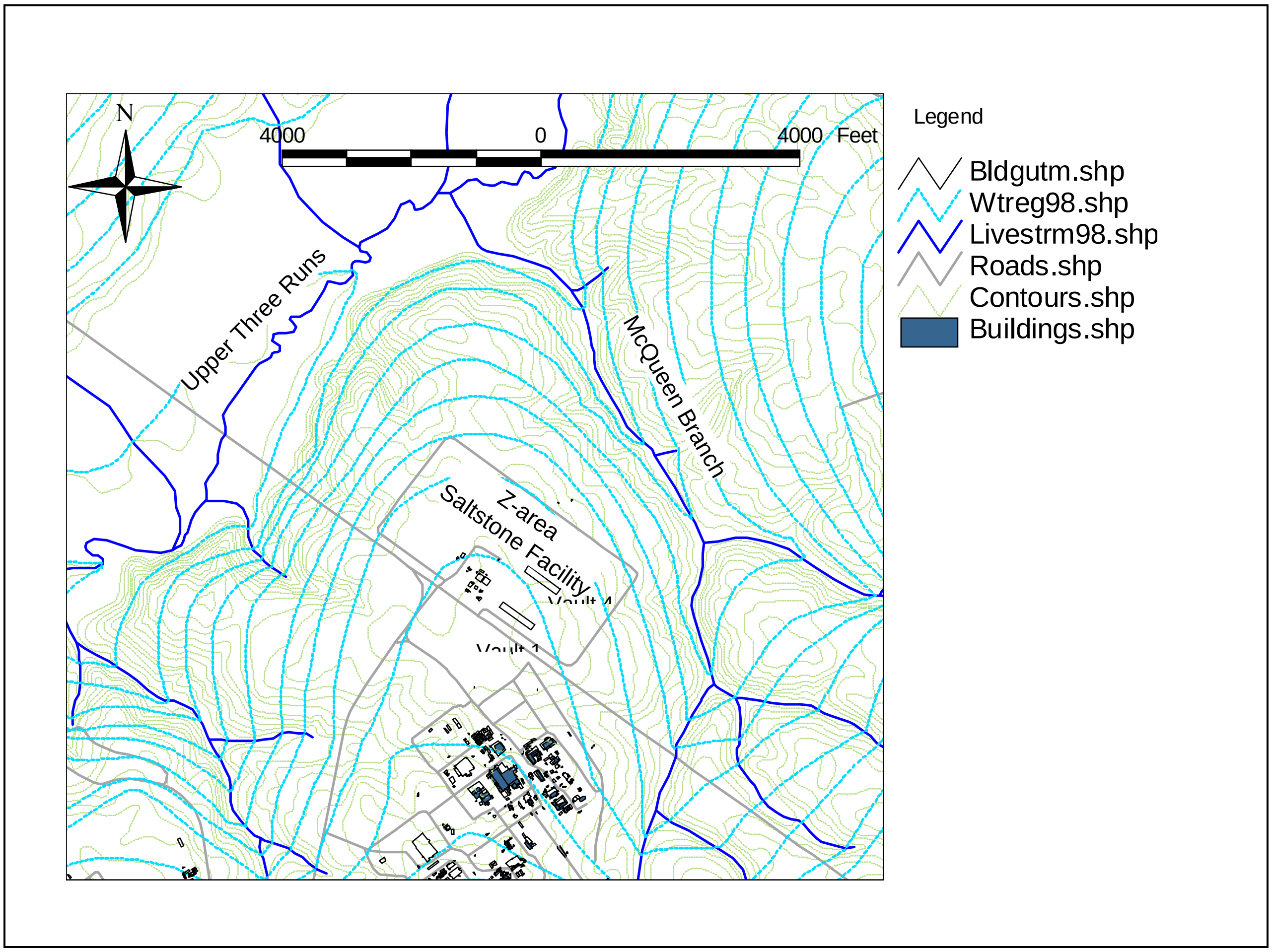


Figure 3-2. Aerial View of Vaults #1 and #4 (Cook et al. 2005 Figure 1-1)

SDF Closure Cap Scoping Level Concept

Final closure of the entire SDF will occur at the end of the 30-year operational period. Final closure will consist of site preparation and construction of an integrated closure system composed of one or more closure caps installed over all the vaults and a drainage system. Final closure is primarily intended to physically stabilize the site, minimize infiltration, and provide an intruder deterrent. Final closure will take into account the vault characteristics and location, disposition of non-disposal structures and utilities, site topography and hydrogeology, potential exposure scenarios, and lessons learned implementing other closure systems, including other Savannah River Site (SRS) facilities and Uranium Mill Tailings sites.

Since the SDF is currently in the initial phase of its 30-year operation period, contains only two existing vaults, and will require an unspecified number of additional vaults on a yet to be determined layout, the information provided herein on the closure cap is appropriately a scoping level concept. That is, it provides sufficient information for planning purposes and to evaluate the closure cap configuration relative to its constructability and functionality, but it is not intended to constitute final design (i.e., final drawings, plans, and specifications). Final design will not be performed until near the end of the operational period prior to actual installation of the closure cap. An independent Professional Engineer will be retained by SRS to certify that the SDF closure system has been constructed in accordance with the approved closure plan and the final drawings, plans, and specifications at the time of closure. The closure cap, installed above each vault, will consist of the layers outlined in Table 3-1 from top to bottom (also see Figure 3-3). Figure 3-4 provides scoping concepts for the side slopes and toes of the closure cap.

Table 3-1. Generic SDF Closure Cap Configuration over Vaults (Phifer and Nelson 2003 Table 4.7-1)

Layer	Thickness (inches)
Vegetation	Not applicable
Topsoil	6
Upper Backfill	30
Erosion Control Barrier	12
Geotextile Filter Fabric	-
Middle Backfill	12
Geotextile Filter Fabric	-
Upper Drainage Layer	12
Upper Geosynthetic Clay Liner (GCL)	0.2
Lower Backfill	58.65 (minimum)
Geotextile Fabric	-
Lower Drainage Layer	24
Lower Geosynthetic Clay Liner (GCL)	0.2

Figure 3-3. Generic SDF Closure Cap Configuration over Vaults (Phifer and Nelson 2003, Figure 4.7-1)

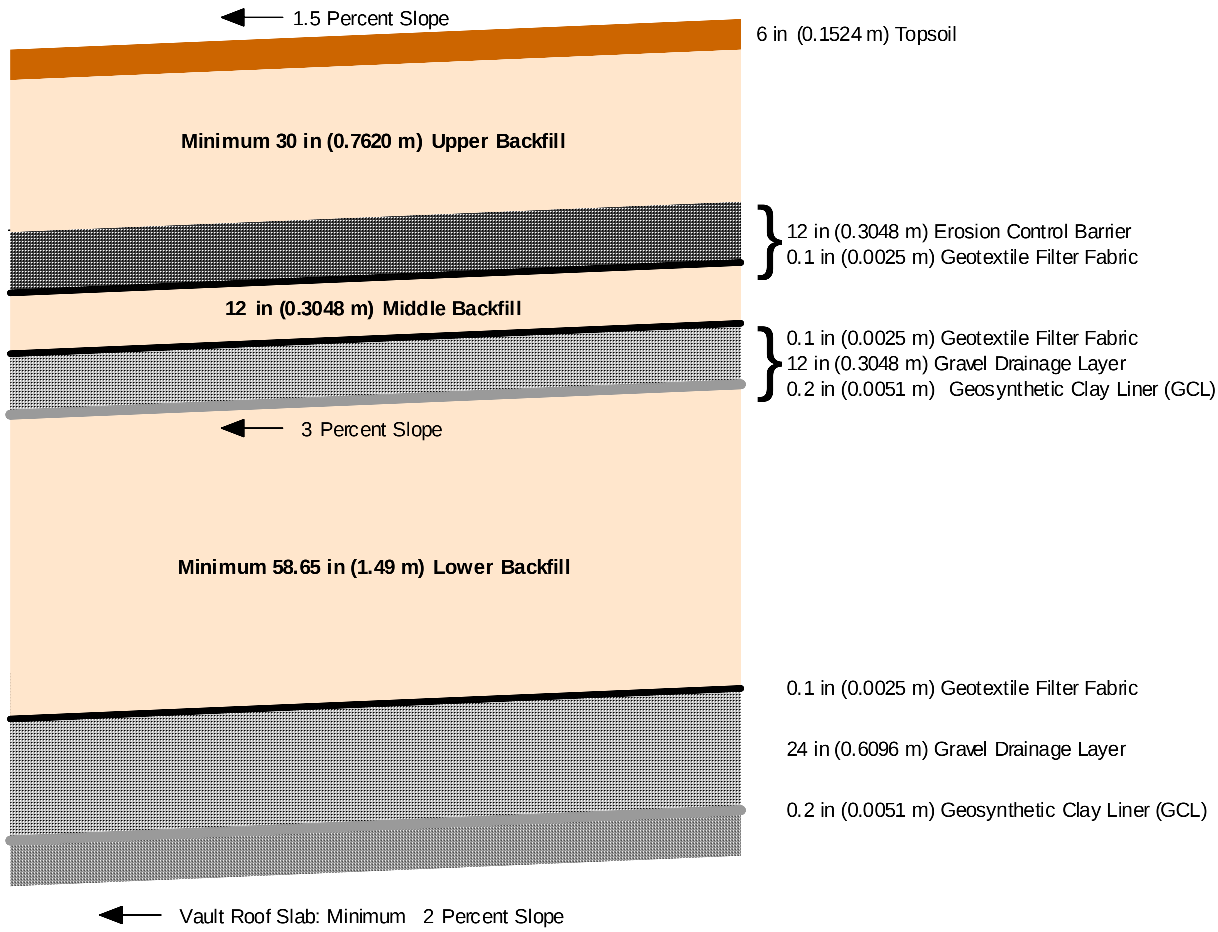
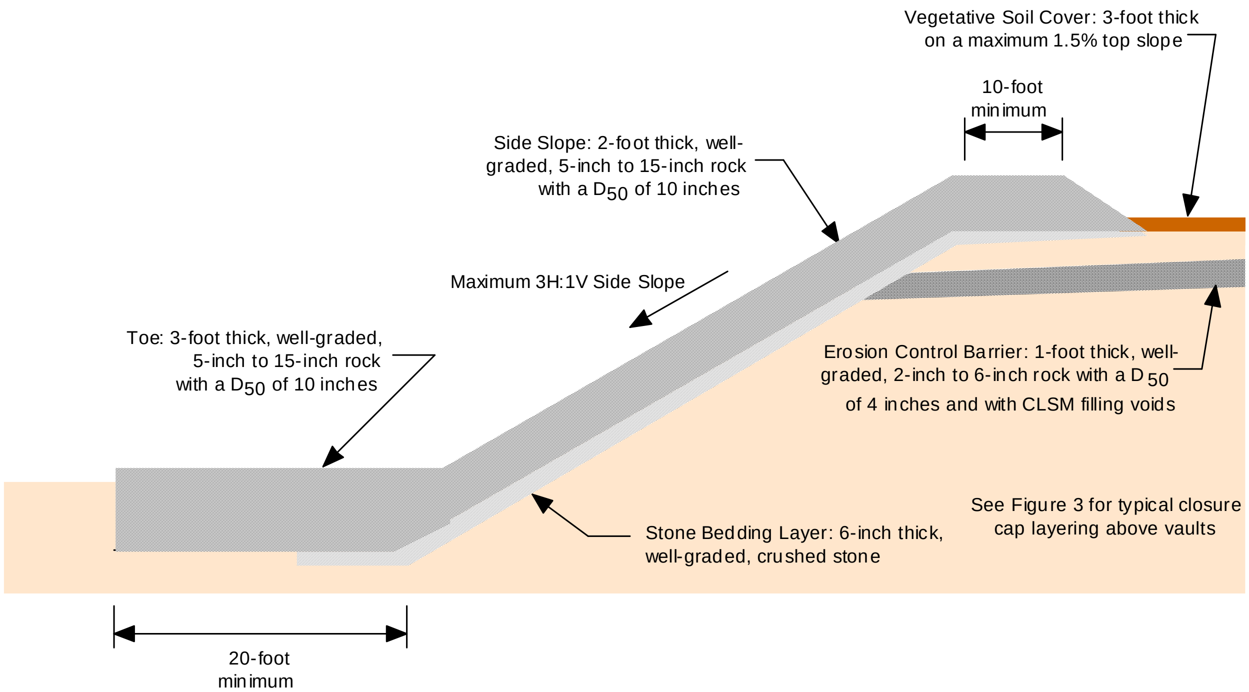


Figure 3-4. Generic SDF Closure Cap Side Slope and Toe Configuration



Scoping level design and construction information associated with each of the Table 1 closure cap layers and for the side slopes and toes are provided in the following discussion.

The vault roof will be appropriately prepared in order to produce a smooth surface for installation of the closure cap on top of it. The existing soils over which the closure cap will be constructed must be prepared prior to closure cap construction. The top 0.08 to 0.15 m (3 to 6 inches) of existing soils in these areas will be removed in order to remove any topsoil and vegetation present. These areas will then be rough graded to establish a base elevation for the closure cap. Finally, these areas will be compacted with a vibratory roller. Areas between vaults will be filled as appropriate with a controlled compacted backfill and/or coarse sand to the vault roofs. See the subsequent sections for information concerning controlled compacted backfill and coarse sand.

The lower geosynthetic clay liner (GCL) will be placed on top of the vault roofs as a hydraulic barrier. The GCL shall have a minimum dry weight of sodium bentonite of 0.75 lbs/ft^2 and a maximum through plane saturated hydraulic conductivity of 5.0E-9 cm/s. The GCL shall be obtained from the manufacturer in rolls, which are on the order of 15 ft wide by 150 ft long. The GCL rolls shall be stored flat and kept dry. The GCL shall be placed directly on top of the vault roof, which would have been appropriately prepared to produce a smooth surface for GCL placement. Therefore, the lower GCL will be sloped at the same slope as the vault roof (i.e., minimum of 2 percent slope). Placement of the rolls of GCL shall consist of unrolling the GCL roll per the manufacturer's directions directly onto the surface of the vault roof, producing a GCL panel. The GCL shall not be placed during periods of precipitation or under other conditions that could cause the bentonite to hydrate prematurely (i.e., prior to placement of a minimum of 1 foot of sand on top of it). GCL panels shall be overlapped a minimum 6 inches on panel edges and a minimum of 1 ft on panel ends. The minimum overlap shall consist of bentonite-containing portions of the GCL overlapping from each panel. The geotextile-only portions of the GCL shall not be included in the minimum overlap. Loose granular bentonite shall be placed between overlapping panels at a rate of ¼ pound per linear foot. The GCL shall be inspected for rips, tears, displacement, and premature hydration prior to placement of the sand on top of it. Any rips, tears, displacement, and premature hydration shall be repaired per the manufacturer's directions prior to placement of the sand on top of it. The overlying 2-foot coarse sand drainage layer shall be placed in no more than two 1-foot lifts on top of the GCL per the manufacturer's directions in order to avoiding damaging the GCL. No equipment used to place the sand shall come into direct contact with the GCL. At the end of each working day, the uncovered edge of the GCL (i.e., that portion that does not have the sand on it) shall be protected with a waterproof sheet that is secured adequately with ballast to avoid premature hydration (USEPA 2001; ASTM 2004a). All work in association with placement of the lower GCL shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The 2-foot thick lower drainage layer will be placed on top of the lower GCL to form a lateral drainage layer and to provide the necessary confining pressures to allow the GCL to hydrate appropriately. The lower drainage layer will be sloped at the same slope as the vault roof and lower GCL (i.e., minimum of 2 percent slope). The lower drainage layer shall consist of coarse sand with a minimum saturated hydraulic conductivity of 1E-1 cm/sec that is free of any materials deleterious to either the underlying GCL or overlying geotextile. The coarse sand drainage layer will extend out from the vaults or be hydraulically connected to drainage layers on the sides and at the base of vaults in order to divert and transport as much infiltrating water as possible away from the underlying vaults. The coarse sand drainage layer shall be placed in no more than two 1-foot lifts on top of the GCL per the GCL manufacturer's directions in order to avoid damaging the GCL. The sand layer will be fine-graded to the required contours. No equipment used to place the sand shall come into direct contact with the GCL; the equipment used to place and fine-grade the sand shall be low ground pressure equipment that is driven on top of the previously placed two foot thick sand layer. No compactive effort shall be applied to the sand layer other than that provided by the equipment used to place and fine grade it. All work in association with placement of the lower drainage layer shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

An appropriate geotextile filter fabric shall be placed on top of the lower drainage layer to provide filtration between the sand and the overlying middle backfill. Koerner 1990 (page 120) defines filtration with a geotextile as:

"The equilibrium fabric-to-soil system that allows for free liquid flow (but no soil loss) across the plane of the fabric over an indefinitely long period of time."

The geotextile filter fabric shall have a minimum thickness of 0.1 in, a minimum through plane saturated hydraulic conductivity of 0.1 cm/s, and an apparent opening size small enough to appropriately filter the overlaying backfill. The geotextile shall be obtained from the manufacturer in rolls, which are on the order of 15 ft wide by 300 ft long or greater. The geotextile rolls shall be stored flat, kept dry, protected from ultraviolet light exposure. The geotextile shall be placed directly on top of the lower drainage layer, which would have been appropriately contoured and determined to be free of materials deleterious to the geotextile. Placement of the rolls of geotextile shall consist of unrolling the geotextile roll down slope per the manufacturer's directions directly onto the surface of the sand, producing a geotextile panel. Adjacent geotextile panels shall be seamed using heat seaming or stitching methods per the manufacturer's directions. The in-place geotextile panels shall be held down with sandbags or approved equivalent until replaced with the overlying middle backfill to prevent the geotextile from being blown out of place. The in-place geotextile panels shall not be exposed to direct sun light for more than 7 days prior to placement of the overlying lower backfill. The in-place geotextile shall be inspected for rips, tears, wrinkling, and displacement prior to placement of the middle backfill on top of it. Any rips, tears, wrinkling, and displacement shall be repaired per the manufacturer's directions prior to placement of the lower backfill on top of it. The initial loose lift of the overlying middle backfill shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoid displacing or damaging the geotextile. No equipment used to place the backfill shall come into direct contact with the geotextile. The feet of any compaction equipment used on the backfill shall be sized so that compaction of the backfill does not damage the geotextile (Koerner 1990 Section 2.11; ASTM 1988). All work in association with placement of this geotextile filter fabric shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The lower backfill is controlled compacted backfill that will be utilized to create the required contours and provide structural support for the rest of the overlying closure cap. It will be used to produce a slope of 3 percent for the overlying upper GCL and upper drainage layer and produce the maximum 3:1

side slopes of the closure cap. Therefore the thickness of this lower backfill layer will vary, but in all cases it will have a minimum thickness of 4.9 ft (58.65 inches) over all vaults. The maximum thickness will depend upon the closure cap aerial geometry and the drainage paths. This layer is not intended to act as an infiltration barrier, but it is intended to provide a suitable base for installation of the upper GCL. The lower backfill soils will be obtained from on-site sources. Only on-site soil classified as SC or CL (clayey sands or sandy clays with low plasticity) shall be used. Borrow areas will be pre-qualified prior to use. The lower backfill shall be placed in lifts not to exceed 9 inches in uncompacted thickness in areas where hand operated mechanical compaction equipment is used and not to exceed 12 inches in uncompacted thickness in areas where self-propelled or towed mechanical compaction equipment is used. Each lift shall be compacted to at least 90% of the maximum dry density per the Modified Proctor Density Test (ASTM 2002b) or 95% per the Standard Proctor Density Test (ASTM 2000). Each lift shall also be placed within specified tolerances of the optimum moisture content. If the surface of a lift is smooth drum rolled for protection prior to placement of a subsequent lift, that lift will be scarified prior to placement of the subsequent lift to ensure proper bonding between lifts. The top lift, upon which the upper GCL will be placed, shall be proof-rolled with a smooth drum roller to produce a surface satisfactory for placement of the upper GCL. All work in association with placement of the lower backfill shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The upper GCL will be placed on top of the lower backfill as a hydraulic barrier at a slope of 3 percent. The upper GCL material and placement requirements will be the same as those outlined for the lower GCL above. In the case of the upper GCL, the overlying upper drainage layer will consist of only 1 foot of coarse sand. The entire sand layer shall be placed in a single lift on top of the GCL per the manufacturer's directions in order to avoiding damaging the GCL. There are no other deviations from the material and placement requirements for the lower GCL for the upper GCL. All work in association with placement of the upper GCL shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The 1-foot thick upper drainage layer will be placed on top of the upper GCL to form a lateral drainage layer and to provide the necessary confining pressures to allow the GCL to hydrate appropriately. The upper drainage layer will be sloped at the same slope as the lower backfill and upper GCL (i.e., a 3 percent slope). The upper drainage layer will be hydraulically connected to the overall facility drainage system in order to divert and transport as much infiltrating water as possible through the upper drainage layer to the facility drainage system and away from the underlying vaults. The 1-foot upper drainage layer shall consist of coarse sand with a minimum saturated hydraulic conductivity of 1E-1 cm/sec that is free of any materials deleterious to either the underlying GCL or overlying geotextile. The upper drainage layer shall be placed in a single 1-foot lift on top of the upper GCL per the GCL manufacturer's directions in order to avoiding damaging the GCL. The remainder of the installation requirements are identical to those of the lower drainage layer. All work in association with placement of the upper drainage layer shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

An appropriate geotextile filter fabric shall be placed on top of the upper drainage layer. The materials and placement method for this geotextile filter fabric is identical to that placed on top of the lower drainage layer. All work in association with placement of this geotextile filter fabric shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The middle backfill will be a 1-ft thick layer used to store water for evapotranspiration. The materials and placement method for the middle backfill is identical to that of the lower backfill. All work in association with placement of the middle backfill shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

An appropriate geotextile fabric shall be placed on top of the middle backfill and below the erosion barrier to prevent the erosion barrier stone from penetrating into the middle backfill and as an additional measure to prevent piping of the middle backfill through the erosion barrier voids. The geotextile fabric material shall conform to the requirements of ASTM 2002a and AASHTO 2005. Although this geotextile fabric has a different material requirement and a different function than the previous geotextiles, the placement method of this geotextile is essentially identical to that of the previous geotextile filter fabrics placed on top of the drainage layers. The overlying erosion barrier shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoid displacing or damaging the geotextile. No equipment used to place the erosion barrier shall come into direct contact with the geotextile. All work in association with placement of this geotextile shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The erosion barrier will be placed on top of the middle backfill and overlying geotextile fabric to form a barrier to erosion and gully formation (i.e., stabilization of the top slopes) and to provide minimal water storage for evapotranspiration. The erosion barrier rock has been sized based upon the Probable Maximum Precipitation (PMP) and the methodology outlined by Abt and Johnson 1991 and Johnson 2002 (see Appendix A of this response for the calculations). Based upon these calculations, a one-foot thick layer of well-graded 2-inch to 6-inch rock with a D_{50} (i.e., median size) of 4 inches has been selected as the nominal rock gradation for use in the erosion barrier. This gradation is consistent with Type B riprap from Table F-3 of Johnson 2002 or Size R-20 riprap from Table 1 of ASTM 1997. The stone shall conform to one of these three stone gradations. The exact gradation utilized shall be determined by availability and economics. Consistent with the recommendations of Johnson 2002 and ASTM 1997, the rock shall be angular, shall have a minimum specific gravity of 2.65, and shall be considered durable per the criteria outlined below:

- The rock shall be dense, sound, resistant to abrasion, free of clays, and free of cracks, seams, and other defects as determined by a petrographic examination (ASTM 2003a).
- Specific gravity (ASTM 2004b), absorption (ASTM 2004b), sodium sulfate soundness (ASTM 2005), Los Angeles abrasion (ASTM 2003b), Schmidt Rebound Hardness-ISRM Method (Johnson 2002) tests shall be performed on the rock. Based upon these tests and the scoring methodology outlined by Johnson 2002, the rock shall have a quality score of 80 or greater.

The stone shall be handled, loaded, transported, stockpiled, and placed consistent with the requirements outlined in ASTM 2002a and Johnson 2002. The stone shall be handled, loaded, transported, stockpiled, and placed in a manner that prevents breakage and segregation of the stone into various sizes. The stone shall be placed in a single 1-foot lift on top of the middle backfill and overlying geotextile fabric by dumping and spreading with heavy equipment. The stone shall be placed in a manner that achieves a reasonably well-graded distribution of stones, a fairly consistent thickness (i.e. 0.9 to 1.25 feet), and a densely packed, wedged together, firmly interlocked layer. No equipment used to place the stone shall come into direct contact with the underlying geotextile; the equipment used to place the stone shall be low ground pressure equipment that is driven on top of the previously placed 1 foot thick stone. The only compactive effort applied to the stone shall be that provided by the equipment used to place it and a minimum of two passes of a Caterpillar D6 tracked bulldozer or equivalent. In order to prevent the loss of overlying material into the erosion barrier and to reduce the saturated hydraulic conductivity of the erosion barrier layer, the rock will be filled with a Controlled Low Strength Material (CLSM) or Flowable Fill (Phifer and Nelson 2003). After placement of the stone, CLSM or Flowable Fill shall be applied on top of the stone in a manner that allows the CLSM or Flowable Fill to penetrate into all the voids within the stone layer. The flow consistency of the CLSM or Flowable Fill will be strictly controlled to ensure that it penetrates into all the voids within the stone layer (ASTM 2004c). Alternate methods of erosion barrier placement similar to the placement of roller-compacted concrete shall be considered. All work in association with placement of the erosion barrier shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The upper backfill will be a minimum 2.5-ft thick layer used to bring the elevation of the closure cap up to that necessary for placement of the topsoil and to produce a slope of 1.5 percent for the overlying topsoil. The upper backfill will also store water for evapotranspiration. The materials and placement method for the upper backfill is essentially identical to that of the lower backfill. The initial loose lift of the upper backfill shall be placed in a single lift on top of the erosion control barrier in order to avoiding damaging the erosion control barrier. No equipment used to place the upper backfill shall come into direct contact with the erosion control barrier. It shall be driven only on top of previously placed backfill. The feet of any compaction equipment used on the backfill shall be sized so that during compaction of the backfill the feet do not directly run on the erosion control barrier. The upper backfill will be fine graded to the required contours. All work in association with placement of the upper backfill shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The uppermost soil layer of the closure cap shall consist of soils capable of supporting a vegetative cover (i.e., topsoil). It will be placed at a maximum 1.5 percent slope in order to provide a stable slope that will prevent the initiation of gullying (see Appendix A of this response for the calculations based upon the Probable Maximum Precipitation (PMP) and the methodology outlined by Johnson 2002). The topsoil, in conjunction with the vegetative cover, will store water and promote evapotranspiration. The topsoil shall be placed in a single 0.5-ft lift on top of the upper backfill. The equipment used to place and fine grade the topsoil shall be low ground pressure equipment. No compactive effort shall be applied to the topsoil other than that provided by the equipment used to place and fine grade it. Measures shall be taken to minimize erosion of the topsoil layer prior to the establishment of the vegetative cover. Any such erosion shall be repaired by the installation subcontractor until such time as the vegetative cover has been established and the closure cap has been accepted as constructed per the approved drawings, plans, and specifications by the Professional Engineer providing certification of the closure cap construction. All work in association with placement of the topsoil shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

A vegetative cover will be established to promote runoff, minimize erosion, and promote evapotranspiration. The topsoil will be fertilized, seeded, and mulched to provide a vegetative cover. The initial vegetative cover shall be a persistent grass such as Bahia. This initial grass will provide erosion control while the final vegetative cover is being established. During seeding and establishment of the initial grass, appropriate mulch, erosion control fabric, or similar substances will protect the surface. The area will be repaired through transplanting or replanting to ensure that a self-maintaining cover is developed. If it is determined that bamboo is a climax species that prevents or greatly slows the intrusion of pine trees, it will be planted as the final vegetative cover. Pine trees are typically assumed to be the most deeply rooted naturally occurring climax plant species at SRS, which will degrade the GCL through root penetration, whereas bamboo is a shallow-rooted species, which will not degrade the GCL. Additionally, bamboo evapotranspirates year-round in the SRS climate, minimizes erosion, and can sustain growth with minimal maintenance. A study conducted by the U.S. Department of Agriculture (USDA) Soil Conservation Service has shown that two species of bamboo (Phyllostachys bissetii and Phyllostachys rubromarginata) will quickly establish a dense ground cover (Salvo and Cook 1993). All work in association with the vegetative cover shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The toe of closure cap side slopes will consist of a riprap layer to stabilize the side slope rip rap, provide erosion protection at the toe, transition flow from the side slope to adjacent areas, and provide gully intrusion protection to the embankment. The toe riprap will extend out from the toe of the side slope a minimum of twenty feet (see Figure 3-4). The toe riprap has been sized based upon the Probable Maximum Precipitation (PMP) and the methodology outlined by Johnson 2002 (see Appendix A of this response for the calculations). Based upon these calculations, a three-foot thick layer of well-graded 5-inch to 15-inch rock with a D_{50} (i.e., median size) of 10 inches, which extends out 20 feet from the bottom of the side slope, has been selected as the nominal riprap gradation for use at the toe. This gradation is consistent with Type D riprap from Table F-3 of Johnson 2002 or Size R-150 riprap from Table 1 of ASTM 1997. The stone shall conform to one of these three stone gradations. The exact gradation utilized shall be determined by availability and economics.

Consistent with the recommendations of Johnson 2002 and ASTM 1997, the toe riprap shall be angular, shall have a minimum specific gravity of 2.65, and shall be considered durable per the criteria outlined below:

- The rock shall be dense, sound, resistant to abrasion, free of clays, and free of cracks, seams, and other defects as determined by a petrographic examination (ASTM 2003a).
- Specific gravity (ASTM 2004b), absorption (ASTM 2004b), sodium sulfate soundness (ASTM 2005), Los Angeles abrasion (ASTM 2003b), Schmidt Rebound Hardness-ISRM Method (Johnson 2002) tests shall be performed on the rock. Based upon these tests and the scoring

methodology outlined by Johnson 2002, the rock shall have a quality score of 80 or greater.

The toe riprap shall be handled, loaded, transported, stockpiled, and placed consistent with the requirements outlined in ASTM 2002a and Johnson 2002. The riprap shall be handled, loaded, transported, stockpiled, and placed in a manner that prevents breakage and segregation of the stone into various sizes. The riprap shall be placed in a single 3-foot lift by dumping and spreading with heavy equipment. The stone shall be placed in a manner that achieves a reasonably well-graded distribution of stones, a fairly consistent thickness (i.e. 2.7 to 3.75 feet), and a densely packed, wedged together, firmly interlocked layer. The only compactive effort applied to the stone shall be that provided by the equipment used to place it and a minimum of two passes of a Caterpillar D6 tracked bulldozer or equivalent. All work in association with placement of the toe riprap shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

The closure cap side slopes will be placed at a maximum three horizontal to one vertical (3H:1V, 33.3 percent, or 19.5 degrees) and have a riprap surface with an underlying gravel bedding layer to prevent gully formation on the side slopes and to provide long-term slope stability. The side slope riprap and underlying gravel bedding layer will extend from the toe of the side slope up the side slope to a minimum ten feet onto the top slope (see Figure 3-4). The stone bedding layer shall consist of a six inch thick layer of well-graded crushed stone with either the gradation shown in Table F-4 of Johnson 2002 or that of Figure 8 of ASTM 1997 (i.e., FS-2 filter/bedding stone). The side slope riprap has been sized based upon the Probable Maximum Precipitation (PMP) and the methodology outlined by Abt and Johnson 1991 and Johnson 2002 (see Appendix A for the calculations). Based upon these calculations and in order to use only one riprap size for both the toe and side slope, a two foot thick layer of well-graded 5-inch to 15-inch rock with a D_{50} (i.e., median size) of 10 inches has been selected as the nominal riprap gradation for use on the side slopes. This gradation is consistent with Type D riprap from Table F-3 of Johnson 2002 or Size R-150 riprap from Table 1 of ASTM 1997. The stone shall conform to one of these three stone gradations. The exact gradation utilized shall be determined by availability and economics. The riprap gradation for both the slide slope and toe shall be the same.

Consistent with the recommendations of Johnson 2002 and ASTM 1997, both the bedding stone and riprap shall be angular, shall have a minimum specific gravity of 2.65, and shall be considered durable per the criteria outlined below:

- The rock shall be dense, sound, resistant to abrasion, free of clays, and free of cracks, seams, and other defects as determined by a petrographic examination (ASTM 2003a).

- Specific gravity (ASTM 2004b), absorption (ASTM 2004b), sodium sulfate soundness (ASTM 2005), Los Angeles abrasion (ASTM 2003b), Schmidt Rebound Hardness-ISRM Method (Johnson 2002) tests shall be performed on the rock. Based upon these tests and the scoring methodology outlined by Johnson 2002, the rock shall have a quality score of 80 or greater.

Both the bedding stone and riprap shall be handled, loaded, transported, stockpiled, and placed consistent with the requirements outlined in ASTM 2002a and Johnson 2002. The bedding stone and riprap shall be handled, loaded, transported, stockpiled, and placed in a manner that prevents breakage and segregation of the stone into various sizes. The bedding stone shall be placed in a single 6-inch compacted lift on the side slope from the bottom of the slope up by dumping, spreading, and compacting with a rubber-tired or smooth drum roller. The riprap shall be placed in a single 2-foot lift on top of the bedding stone from the bottom of the slope up by dumping and spreading with heavy equipment. The stone shall be placed in a manner that achieves a reasonably well-graded distribution of stones, a fairly consistent thickness (i.e., 1.8 to 2.5 feet), and a densely packed, wedged together, firmly interlocked layer. The only compactive effort applied to the stone shall be that provided by the equipment used to place it and a minimum of two passes of a Caterpillar D6 tracked bulldozer or equivalent. All work in association with placement of the side slope bedding stone and riprap shall be performed in accordance to the approved drawings, plans, and specifications of the final design, which will be produced near the end of the operational period.

An integrated drainage system will be designed and built to handle the runoff from the closure caps and lateral drainage out the closure cap upper drainage layers. The runoff and lateral drainage will be directed to a system of riprap lined ditches, which will be designed in accordance with Johnson 2002. The riprap-lined ditches will direct the water away from the vaults and the SDF as a whole. The riprap-lined ditches will be constructed between individual closure caps and around the perimeter of the SDF. The ditches will discharge into sedimentation basins as necessary for sediment control. The riprap for the ditches has not been sized yet since the SDF is currently in the initial phase of its 30-year operation period, contains only two existing vaults, and will require an unspecified number of additional vaults on a yet to be determined layout. Due to the early phase and lack of a vault layout plan, a detailed drainage system layout cannot yet be produced. Therefore, drainage areas and flows cannot be currently assigned in order to size the riprap for various sized ditches.

Appendix A, Physical Stability Calculations

Scoping level calculations and/or estimations have been made in order to ensure that a physically stable closure cap configuration relative to erosion is provided. Calculations and/or estimations for the following key items are provided below:

- Probable maximum precipitation (PMP) estimation
- Erosion barrier and side slope riprap sizing
- Toe riprap sizing
- Vegetative soil cover slope

Probable Maximum Precipitation Estimation

Estimates of the SRS-specific probable maximum precipitation (PMP) for storm (drainage) areas ranging from 1 to 1000 square miles and rainfall durations from 5 minutes to 72 hours have been made. A PMP is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible over a given storm size area at a particular geographic location. These estimates are summarized in Table 2. The SRS-specific PMP estimates for storm areas of 10, 200, and 1000 square miles and rainfall durations of 6 to 72 hours were based on interpolation from standard maps of generalized, all-season isohyets of PMP presented in Hydrometeorological Report (HMR)-51 (Schreiner and Riedel 1978). The PMP estimates for a 1 square mile area and for rainfall durations less than 6 hours were based on procedures outlined in HMR-52 (Hansen et al. 1982). The 1-hour duration rainfall over storm areas from 1 to 1000 square mile was obtained through interpolation from the standard PMP isohyetal maps. Additional maps presented in HMR-52 were used to obtain SRS-specific scaling factors that were then applied to the 1-hour PMP value to determine 5 and 15-minute amounts. The 1 square mile PMP is considered by HMR-52 equivalent to the rainfall at any point within that area. Therefore, the 1 square mile PMP has been utilized in the subsequent riprap sizing calculations (see below).

Table 2. Estimated Probable Maximum Precipitation for the Savannah River Site (SRS)

Duration	Area (square miles)			
	One	Ten	Two Hundred	One Thousand
5 min	6.2	5.1	2.9	-
15 min	9.7	8.0	4.6	-
1 hr	19.2	15.7	9.1	5.1
6 hr	-	31	23	16.8
12 hr	-	37	28	22.7
24 hr	-	43.5	35	31
48 hr	-	48	38	33
72 hr	-	51.5	42	36

All precipitation values are in inches

Erosion Barrier and Side Slope Riprap Sizing

The riprap for the top slope erosion barrier (i.e., riprap on the top slope which is located 3 feet deep) and the side slopes have been sized per the Abt and Johnson Method (Abt and Johnson 1991 and Johnson 2002 Appendix D Section 2).

Calculate the drainage area of the top slope (TS) and side slope (SS) on a foot-width basis:

TS: slope length = 450 ft (Phifer 2003); slope = 3% (0.03) (Phifer 2003); elevation difference (H) = 450 ft × 0.03 = 13.5 ft

$$A_{TS} = (450 \ ft \times 1 \ ft) / 43560 \ ft^2 / acre = 0.0103 \ acres$$

SS: slope = 33.3% (0.333) maximum (Phifer and Nelson 2003); assume a 20 foot elevation difference between edge of closure cap and immediately surrounding natural ground surface (i.e. H = 20 ft); slope length = 20 ft / 0.333 = 60 ft

$$A_{SS} = (60 \ ft \times 1 \ ft) / 43560 \ ft^2 / acre = 0.0014 \ acres$$

Calculate the time of concentration for the top slope (TS) and side slope (SS) using the Kirpich Method:

$t_c = (11.9 L^3 / H)^{0.385}$, where t_c = time of concentration in hours;
L = drainage length in miles; H = elevation difference in ft

TS: L = 450 ft / 5280 ft/mile = 0.085 miles; H = 13.5 ft

$$t_c = \left(11.9(0.085)^3/13.5\right)^{0.385} = 0.055\ hrs = 3.3\ \text{min}$$

SS: L = 60 ft / 5280 ft/mile = 0.0114 miles; H = 20 ft

$$t_c = 0.055 + \left(11.9(0.0114)^3/20\right)^{0.385} = 0.060\ hrs = 3.6\ \text{min}$$

Calculate the rainfall intensity for the top slope (TS) and side slope (SS):

A rainfall intensity of 6.2 inches with duration of five minutes is taken from Table 2. The rainfall intensity at the time of concentration will be determined by linear interpolation between 0 inches at 0 minutes and 6.2 inches at 5 minutes and converted to inches per hour.

TS: $$I_{3.3\ \text{min}} = \frac{6.2\ in \times 3.3\ \text{min}}{5\ \text{min}} \times \frac{60\ \text{min}/hr}{3.3\ \text{min}} = 74.4\ in/hr$$

SS: $$I_{3.6\ \text{min}} = \frac{6.2\ in \times 3.6\ \text{min}}{5\ \text{min}} \times \frac{60\ \text{min}/hr}{3.6\ \text{min}} = 74.4\ in/hr$$

Calculate the peak flow rate using the rational formula and a flow concentration factor of 5:

$Q_{cal} = FCIA$, where Q_{cal} = calculated flow in cfs; F = flow concentration factor (unitless); C = runoff coefficient (unitless); I = precipitation in in/hr; A = drainage area in acres

A conservative flow concentration factor (F) of 5 has been utilized for both the top slope and the side slope. The factor of 5 has been used for the top slope since it is overlain by a 3-foot thick soil layer which could potentially be subject to gully erosion. It has been used for the side slope, since the top slope feeds into the side slope.

The voids within the stone of the top slope erosion barrier will be filled with a CLSM (i.e., a lean cement/sand/water mixture). Therefore the runoff coefficient (C) will be taken as the lower end of that for concrete (i.e., C = 0.8) (Goldman et al. 1986 Table 4.1). The runoff coefficient for the side slope will also be taken as 0.8 since it is on a barren steep slope (Goldman et al. 1986 Table 4.1).

TS: $$Q_{cal} = FCIA = 5(0.8)(74.4\ in/hr)(0.0103\ acres) = 3.06\ cfs$$

SS: $$Q_{cal} = FCIA = 5(0.8)(74.4\ in/hr)(0.0117\ acres) = 3.48\ cfs$$

Calculate the required size of the riprap using the Abt and Johnson Method (Abt and Johnson 1991 and Johnson 2002 Appendix D Section 2):

$D_{50} = 5.23\ S^{0.43}\ Q_{design}^{0.56}$, where D_{50} = median size of riprap in inches; S = slope in fraction form; $Q_{design} = 1.35\ Q_{failure}$; $Q_{failure} = Q_{cal}$ (flow calculated above in cfs)

The flow at failure ($Q_{failure}$) is the flow required to move the riprap such that the underlying filter fabric or bedding stone is exposed. In order to design for no movement of the riprap, the design flow (Q_{design}) is utilized, which increases the failure flow ($Q_{failure}$) by a factor that represents the experimental ratio of "the unit discharge at movement to unit discharge at failure" (Abt and Johnson 1991).

TS: $Q_{design} = 1.35\ Q_{cal} = 1.35$ (3.06 cfs) = 4.13 cfs

$$D_{50} = 5.23\ S^{0.43}\ Q_{design}^{0.56} = 5.23\ (0.03)^{0.43}\ (4.13\ cfs)^{0.56} = 2.56\ inches$$

SS: $Q_{design} = 1.35\ Q_{cal} = 1.35$ (3.48 cfs) = 4.70 cfs

$$D_{50} = 5.23\ S^{0.43}\ Q_{design}^{0.56} = 5.23\ (0.33)^{0.43}\ (4.70\ cfs)^{0.56} = 7.72\ inches$$

Toe Riprap Sizing

The riprap for the toe has been sized per the Abt Method (Johnson 2002 Appendix D Section 6).

Calculate the peak flow rate off the combined top slope and side slope using the rational formula and a flow concentration factor of 3:

$Q_{cal} = FCIA$, where Q_{cal} = calculated flow in cfs; F = flow concentration factor (unitless); C = runoff coefficient (unitless); I = precipitation in in/hr; A = drainage area in acres

A flow concentration factor of 3 is recommended by Johnson 2002. A flow concentration factor of 5 is not used for the toe riprap although it is used for the top slope and side slope riprap. Since the side riprap has been designed using a flow concentration factor of 5 and design to prevent movement of its riprap, channeling and the formation of gullies in the side slope which feed into the toe should be prevented. Therefore, a flow concentration factor of 3 is deemed appropriate for the toe.

The runoff coefficient, precipitation, and drainage area are the same as that of the side slope.

$$Q_{cal} = FCIA = 3(0.8)(74.4\ in/hr)(0.0117\ acres) = 2.09\ cfs$$

Calculate the required size of the riprap using the Abt Method (Johnson 2002 Appendix D Section 6):

$D_{50} = 10.46\ S^{0.43}\ Q_{cal}^{0.56}$, where D_{50} = median size of riprap in inches; S = slope in fraction form = 0.33 (see above for side slope); Q_{cal} = flow calculated above in cfs

$$D_{50} = 10.46\left(0.33\right)^{0.43}\left(2.09\ cfs\right)^{0.56} = 9.8\ inches$$

Top Slope, Side Slope, and Toe Riprap Summary

Using the Abt and Johnson 1991 method, the required D_{50} (median size) of the top slope riprap was determined to be 2.56 inches. The required D_{50} (median size) of the top slope riprap was determined to be approximately 3 inches by Phifer and Nelson 2003 (Appendix K). These two values are essentially the same. Therefore the previously design erosion barrier (i.e., top slope) consisting of well-graded 2-inch to 6-inch rock with a D_{50} (i.e., median size) of 4 inches is acceptable. Johnson 2002 recommends a riprap layer thickness of not "less than 1.5 times the mean stone diameter (D_{50}) or the D_{100} whichever is greater". NCSU 1991 recommends that the riprap layer thickness be at least 1.5 times the maximum stone diameter (D_{100}). Since the NCSU 1991 criterion is more conservative, it will be utilized. Additionally the voids within the stone layer shall be filled with CLSM or Flowable Fill. The increased stability of this layer produced by filling with CLSM or Flowable Fill has not been taken into consideration in sizing the stone.

Calculate the thickness of the erosion barrier (i.e. top slope):

Thickness = 1.5 (D_{100}) = 1.5 (6 inches) = 9 inches

However, a 9 inch placement is not typical; therefore a 12-inch layer will be utilized.

The required D_{50} (median size) of the side slope riprap was determined to be 7.72 inches, and the required D_{50} (median size) of the toe riprap was determined to be 9.8 inches. Since these two sizes are so close, one D_{50} (median size) will be selected for both the side slope and toe riprap. A well-graded 5-inch to 15-inch rock with a D_{50} (i.e., median size) of 10 inches will be utilized for both the side slope and toe.

Calculate the thickness of the side slope riprap:

Thickness = 1.5 (D_{100}) = 1.5 (15 inches) = 22.5 inches

However, a 22.5 inch placement is not typical; therefore, a 24 inch layer will be utilized.

Johnson 2002 recommends a toe riprap thickness of 3 times the mean stone diameter (D_{50}) and a toe width of 15 times the mean stone diameter (D_{50}).

Calculate the thickness and width of the toe riprap:

Thickness = 3 (D_{50}) = 3 (10 inches) = 30 inches

A 36-inch thickness will be planned.

Calculate the toe width:

Width = 15 (D_{50}) = 15 (10 inches) = 150 inches = 12.5 ft

A width of 20 feet will be planned.

Table 3 provides a summary of the top slope, side slope, and toe riprap requirements

Table 3. Top Slope, Side Slope, and Toe Riprap Requirements Summary

Location	Riprap Requirements
Top slope (i.e., erosion barrier)	A one foot thick layer of well-graded 2-inch to 6-inch rock with a D_{50} (i.e., median size) of 4 inches.[1] Voids within the stone layer shall be filled with CLSM or Flowable Fill.
Side slope	A two-foot thick layer of well-graded 5-inch to 15-inch rock with a D_{50} (i.e., median size) of 10 inches, which extend 10 feet onto the top slope.[2] The riprap shall be underlain with a stone bedding layer consisting of a six-inch thick layer of well-graded crushed stone with either the gradation shown in Table F-4 of Johnson 2002 or that of Figure 8 of ASTM 1997 (i.e., FS-2 filter/bedding stone).
Toe	A three-foot thick layer of well-graded 5-inch to 15-inch rock with a D_{50} (i.e., median size) of 10 inches, which extends out 20 feet from the bottom of the side slope. [2]

1. This gradation is consistent with Type B riprap from Table F-3 of Johnson 2002 or Size R-20 riprap from Table 1 of ASTM 1997.
2. This gradation is consistent with Type D riprap from Table F-3 of Johnson 2002 or Size R-150 riprap from Table 1 of ASTM 1997.

Vegetative Soil Cover Slope

The slope of the vegetative soil cover has been evaluated using the permissible velocity method as outlined by Johnson 2002 Appendix A.

Calculate the peak flow rate using the rational formula and a flow concentration factor of 3:

$Q_{cal} = FCIA$, where Q_{cal} = calculated flow in cfs; F = flow concentration factor (unitless); C = runoff coefficient (unitless); I = precipitation in in/hr; A = drainage area in acres

The rainfall intensity (I) of 74.4 inches/hour and the area (A) of 0.0103 acres determined for the erosion barrier (i.e., top slope) is also applicable to the vegetative soil cover. A flow concentration factor (F) of 3 is recommended by Johnson 2002. The runoff coefficient (C) will be taken as the upper end of that for pasture and woodlands (i.e., C = 0.45) (Goldman et al. 1986 Table 4.1).

$$Q_{cal} = FCIA = 3(0.45)(74.4\ in/hr)(0.0103\ acres) = 1.03\ cfs$$

Calculate the flow depth using the Manning Equation:

$y^{5/3} = \dfrac{Q_{cal}n}{1.486\ S^{1/2}}$, where y = depth in feet; Q_{cal} = flow in cfs (see value above); n = Manning coefficient of roughness (unitless); S = slope in fraction form

It is planned that the slope of the vegetative soil cover will be between 0 and 5 percent and that it will be vegetated with Bahia grass or equivalent (bamboo and pine trees are considered better than Bahia grass in terms of erosion protection). Based on the use of Bahia grass and a 0 to 5 percent slope, a maximum permissible velocity (MPV) of 5 fps has been obtained from Exhibit 7-3 of SCS 1984.

Based upon Bahia grass, a retardance classification of C has been obtained from Exhibit 7-2 or SCS 1984. Determine the product of velocity (V) and hydraulic radius (R) based upon a unit width of flow of 1-foot (this is equal to the R since there are no sides in this case) and a MPV of 5 fps:

VR = 1 ft × 5 ft/s = 5 ft^2/s

Based upon a VR of 5 ft^2/s and a retardance classification of C, a Manning coefficient of roughness (n) of 0.039 has been obtained from Exhibit 7-1 of SCS 1984.

A slope of 3 percent (i.e. 0.03) has been utilized for the design of the erosion barrier (see above). It is assumed that in order to minimize the thickness of the upper backfill and topsoil layers that the surface of each would also be at a 3 percent slope.

$$y^{5/3} = \frac{Q_{cal}\, n}{1.486\ S^{1/2}} = \frac{(1.03\ cfs)(0.039)}{1.486\ (0.03)^{1/2}} = 0.156$$

$$y = (0.156)^{3/5} = 0.33\ ft$$

Calculate permissible velocity (V_p) for the slope based upon the depth of flow using the velocity correction factors provided by Johnson 2002 on page A-5:

For a depth of flow of 0.33 ft, the velocity correction factor (CF) is 0.55 (a depth of 0.25 ft has a correction factor of 0.5 and a depth of 0.4 ft has a correction factor of 0.6; a depth of 0.33 ft is essentially half-way between).

V_p = CF × MPV = 0.55 × 5 fps = 2.75 fps

Calculate the actual velocity (V_a) and compare to the permissible velocity (V_p):

$V_a = Q_{cal}/y$ = 1.03 cfs / 0.33 ft = 3.12 fps

V_a = 3.12 fps > V_p = 2.75 fps; therefore, the 3 percent slope cannot be considered a stable slope to prevent the initiation of gullying for the precipitation considered (i.e. 74.4 in/hour).

Determine the slope that would be considered a stable slope to prevent the initiation of gullying for the precipitation considered (i.e., 74.4 in/hour):

Calculate the flow depth using the Manning Equation with a slope of 0.015 (i.e., half the 3 percent slope originally considered):

$$y^{5/3} = \frac{Q_{cal}\, n}{1.486\ S^{1/2}} = \frac{(1.03\ cfs)(0.039)}{1.486\ (0.015)^{1/2}} = 0.221$$

$$y = (0.221)^{3/5} = 0.40\ ft$$

Calculate permissible velocity (V_p) for the slope based upon the depth of flow using the velocity correction factors provided by Johnson 2002 on page A-5:

For a depth of flow of 0.40 ft, the velocity correction factor (CF) is 0.6.

V_p = CF × MPV = 0.6 × 5 fps = 3.0 fps

Calculate the actual velocity (V_a) and compare to the permissible velocity (V_p):

$V_a = Q_{cal}/y$ = 1.03 cfs / 0.4 ft = 2.58 fps

V_a = 2.58 fps < V_p = 3.0 fps; therefore, a 1.5 percent slope is considered a stable slope to prevent the initiation of gullying for the precipitation considered (i.e., 74.4 in/hour) and will be utilized as the slope for the topsoil layer.

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Salvo, S.K., and Cook, J.R., 1993, *Selection and Cultivation of Final Vegetative Cover for Closed Waste Sites at the Savannah River Site, SC,* WSRC-MS-92-513, Westinghouse Savannah River Company, Aiken, South Carolina.

Schreiner, L. C. and Riedel, J. T., 1978, *Probable Maximum Precipitation Estimates, United States East of the 105th Meridian, Hydrometeorological*

Report 51, National Oceanic and Atmospheric Administration, National Weather Service, Office of Hydrology, Hydrometeorological Branch and U.S. Army Corps of Engineers, p. 87.

SCS (Soil Conservation Service), 1984, *Engineering Field Manual*, fourth printing, U.S. Department of Agriculture, Soil Conservation Service.

USEPA (United States Environmental Protection Agency) 2001, *Geosynthetic Clay Liners Used in Municipal Solid Waste Landfills*, Solid Waste and Emergency Response, EPA530-F-97-002, United States Environmental Protection Agency, Washington, DC.

WSRC (Westinghouse Savannah River Company), 1992, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 4 (8/17/05): ***Sensitivity Analyses Bases***

Provide Bases for values used in the sensitivity analyses described in the handout.

SRS Response: The response to NRC Action Item 7 (7/27/05) addresses the bases for degraded values of concrete and Saltstone due to higher hydraulic conductivities. A number of sensitivity cases have been run in response to questions raised in the review of the Salt Disposal program that focused on this topic (See NRC Action Item 10 (8/17/05)). Final saturated hydraulic conductivities ranging from 1E-8 to 1E-6 cm/s were used to investigate the effect this change had on the calculated all-pathways dose. These cases showed that there is an increase in the calculated dose as the degradation rates increase; however, over the range of values considered, the calculated doses were still below the performance objective.

Action Item 5 (8/17/05): ***Vault Hydraulic Conductivity References***

Provide references for hydraulic conductivity for the vaults (RAI 32).

SRS Response: A literature review was performed to provide a range of hydraulic conductivities and permeability coefficients for concretes and cement pastes. The key parameters reported in the reference literature include hydraulic conductivity, K_h (cm/s), and permeability coefficient, K_p or $k_{permeability}$ (m^2). These two proportionality coefficients are derived from two different forms or expressions of Darcy's Law. The relationship between hydraulic conductivity and permeability is defined following Table 5-1 in this response.

Representative hydraulic conductivity and permeability coefficient values are listed in Table 5-1. For comparison, the reported values are listed and were converted to hydraulic conductivity (K_h expressed in cm/seconds). Selected references providing hydraulic conductivities and permeability coefficients for similar materials to that of the Saltstone vault concrete are provided in this response.

Data for cement pastes were included because, for a given water to cement ratio (porosity) and suite of cement and pozzolan starting materials, pastes represent the lower range of both measured hydraulic conductivity (~1E-13 cm/s) and theoretical hydraulic conductivity values (≤1E-14 cm/s) for cementitious composites, such as, concrete and mortar, which contain aggregates.

Data for concrete samples measured in the selected references ranged from 1E-07 cm/s to 3E-12 cm/s. The lowest value, 3E-12 cm/s, was reported for a high performance concrete with a water to cement ratio of 0.35, mineral admixtures, and a super plasticizer. The highest value, 1E-07 cm/s, was reported for an actual cored structure in a field setting. Some of the data were collected from samples prepared and cured in the laboratory under controlled conditions, while other data were obtained from cores taken from structural concrete. Samples were stated to be, or assumed to be, saturated unless otherwise stated.

Saturated hydraulic conductivities for E-Area and Z-Area concrete were measured by Core Laboratories, Inc. Values ranged from 7.4E-13 to 1E-12 cm/s and 1.1E-10 to 2.3E-09 cm/s (Vault 1), respectively. The hydraulic conductivity of concrete depends not only on the ingredients and proportions of the ingredients, but also on the workmanship. The E-Area Vaults were built with a special blended (cement, slag, fly ash) mix design and special curing procedures were implemented to assure high quality workmanship. Z-Area Vaults 1 and 4 were also built with a blended cement (cement and slag) concrete mix design. However, the degree of workmanship (i.e., curing techniques) on Vault 1 was less rigorous than that used for the E-Area Vaults. Since the degree of workmanship for Z-Area Vault 4 was considerably more rigorous, permeability values for E-Area concrete rather than for Z-Area Vault 1 concrete were used in the Special Analysis for Vault 4.

Because of experimental difficulties in measuring water flow through low permeable pastes and concretes (<1E-10 cm/s), permeability coefficients were not measured in the concrete test program performed by the Canadian Atomic Energy Commission to support design of radioactive waste disposal vaults (Beaudoin 2005). Researchers at the Canadian National Resource Council developed a pulse (pressure pulse) decay method for measuring permeability as an alternative to using pressure flow through techniques for the Canadian radioactive waste repository concrete assessment program. However, testing was not carried out on the concretes prepared for the concrete test program (Beaudoin 2005).

Table 5-1. Permeability Coefficient and Hydraulic Conductivity Literature Values for Concretes and Cement Pastes

Reference	Sample description	Reported Value $K = K_h$ (cm/s) or (m/s) $k = K_{permeability}$ (m^2)	Hydraulic Conductivity K_h (cm/s)
Basheer, P. A. M., 2001. "Permeation Analysis," chapter in Handbook of Analytical Techniques in Concrete Science: Technology Principles, Techniques and Applications, eds. Ramachandran, V. S. and Beaudoin, J. J., Noyes Publications, NJ, USA, p. 658-737, (referenced p. 704), 2001; Data taken from Hope, B. B. and Malhotra, V. M., "The Measurement of Concrete Permeability," Canadian Journal of Civil Engineering, 11:287 – 292 (1984).	Water permeability of concrete Water/cement = 0.35, air content = 4.0 vol. %, compressive strength = 33.1 MPa Water/cement = 0.45, air content = 5.8 vol. %, compressive strength = 26.1 MPa	K= 3.7E-14 (m/s) K= 1.26E-13 (m/s)	3.7E-12 1.26E-11
El-Dieb, A. S. and Hooton, R. D., "Evaluation of the Katz-Thompson Model for Estimating the Water Permeability of Cement-Based Materials from Mercury Intrusion Porosimetry Data," Cement and Concrete Research, v. 24, N. 3, p. 443-455 (referenced p.450, 452), 1994.	12 concretes with a range of aggregate, sand and cementitious ingredients including silica fume and superplasticizers, w/c 0.9 to 0.28. (Lowest w/c not directly related to lowest K measurement.) Permeability coefficients were also calculated for the 12 mixes based on pore size and structure. See p. 452	K = 6.14E-13 (m/s) to K = 2.8E-13 (m/s)	6.1E-11 to 2.8E-11
Osborne G. J., 1989. "Carbonation and Permeability of Blast Furnace Slag Cement Concretes from Field Structures," Proceedings of the Third International Conference Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, 1989, V. M. Malhotra, ed., Trondheim, Norway, v. 2, p. 1209 – 1237 (referenced p. 1233 and 1234), ACI SP 114-59.	Water permeability measurements on sections of ten concrete cores from structures in the Midlands, England. Water permeability measurement on sections of 10 concrete cores from structures in North East England.	*k* = 1.1E-16 (m^2) to *k* = 5E-20 (m^2) *k* = 5.6E-17 (m^2) to *k* = 1.8E-19 (m^2)	1.1E-07 to 4.9E-11 5.4E-08 to 1.7E-10
Snyder, K. A., 2003. Condition Assessment of Concrete Nuclear Structures Considered for Entombment, NISTIR 7026, U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, Version 20030108:1545, July 2003 (referenced page, p.5).	Permeability reported for typical concrete	*k* = 1E-17 (m^2) *k* = 1E-18 (m^2)	9.8E-09 9.8E-10
U.S. Department of the Interior, Water and Power Resources Service, Concrete Manual, 8th ed., U.S. Government Printing Office, Washington D.C., 1975 reprinted 1981, (referenced page, p.37).	Concrete with 3 inch aggregate and a water to cement ratio of 0.5. Concrete with 3 inch aggregate and a water to cement ratio of 0.45. (Values for concretes with 1.5 inch aggregate are slightly less than for 3 inch aggregate at corresponding w/c ratios.)	K ~ 3E-04 (ft/yr) K ~ 1E-04 (ft/yr)	~ 2.9E-10 ~ 9.7 E-11

Reference	Sample description	Reported Value K = K_h (cm/s) or (m/s) *k*= $K_{permeability}$ (m^2)	Hydraulic Conductivity K_h (cm/s)
Hearn, N. and Figg, J., 2001. "Transport Mechanisms and Damage: Current Issues in Permeation Characteristics of Concrete," Chapter in Materials Science of Concrete VI, ed. by Mindess, S. and Skalny, J., 2001, p. 327 – 375 (referenced p. 358).	Saturated concrete w/c = 0.56	K ~ 3E-14 (m/s) to K ~ 7E-12 (m/s)	3E-12 to 7E-10
Hearn, N. Detwiler, R. J., and Sframeli, C., 1994. Permeability and Microstructure of Three Old Concretes, Cement and Concrete Research, V. 24, no. 4, p. 633-640 (referenced p. 637 and 638).	26 year old concrete , w/c = 0.9, porosity = 0.19, Water saturated Water to cement ratio = 0.51, Cured for about 700 hours.	K = 4E-13 (m/s) to K = 2E-12 (m/s) K = 1E-13 (m/s)	4E-11 to 2E-10 1E-11
Hearn, N. A., 1990. "Recording Permeameter for Measuring Time-Sensitive Permeability of Concrete," in Advances in Cementitious Materials, Ceramic Transactions, v.16, p. 463-475 (referenced p. 467-471), S. Mindess ed., American Ceramic Society, Westerville, OH.	26 year old concrete, w/c = 0.9, Water saturated Same as above dried and re-saturated samples Same as above oven dried and re-saturated	*k* = 2.2E-19 m^2 to 1 E-19 m^2 *k* = 2.2E-19 m^2 to 2E-20 m^2 *k* = 1.8E-18 to <1E-20 m^2	2.16E-10 to 1E-10 2.16 E-10 to 2E-11 1.77E-09 to < 9.8E-12
Walton, J. C., Plansky, L.E. and Smith R. W., Models for Estimation of Service Life of Concrete Barriers in Low-Level Radioactive Waste Disposal, NUREG/CR-5542, EGG-2597, Prepared for Division of Engineering, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington DC 20555, NRC FIN A6858, September, 1990 (referenced page, p. 4).	Hydraulic conductivity reported for flow through gel pores taken from Powers, T. C. Structure and Physical Properties of Hardened Portland Cement Paste, J. A. Ceramic Soc., v. 41, n. 1, p. 1-6, 1958. Permeability of concrete is a function of capillary porosity which is a function of the water to cement ratio and degree of hydration. Typical cement paste permeability = 20 to 100 times greater than the min. Concrete hydraulic conductivity with low w/c.	K = 7E-16 (m/s) K = 7E-14 (m/s) (100 times minimum) K < 1E-12 (m/s)	7E-14 (Gel) 7E-12 (Paste) <1E-10 (Concrete)

Reference	Sample description	Reported Value **K = K_h (cm/s) or (m/s)** ***k*= $K_{permeability}$ (m^2)**	Hydraulic Conductivity **K_h (cm/s)**
Luping, T. and Nilsson, L., A Study of the Quantitative Relationship Between Permeability and Pore Size Distribution of Hardened Cement Pastes, Cement and Concrete Research, V. 22, No. 4, p. 541 to 550, (referenced pages, p. 545 to 547), July 1992.	Experimentally measured permeability coefficient for hardened cement pastes 3E-13 to 3E-10 m/s	K= 1E-13 to 4E-10 (m/s)	1E-11 to 4E-08 Paste Values
Powers, T.C., Copeland, L.E., Hayes, J.C., and Mann, H.M., 1954/1955. Permeability of Portland Cement Paste, Portland Cement Association Bulletin 53, April 1955, Portland Cement Association, Skokie, IL, USA, and J. of the American Concrete Institute, vol. 51, p. 285 to 298, Nov. 1954. (referenced page, p. 297).	Mature cement paste with w/c ratio of 0.3 Mature cement paste with w/c ration of 0.38 Mature cement past with w/c ratio of 0.7	K = 1E-13 (cm/s) K = 3E-13 (cm/s) K = 1E-10 (cm/s)	K = 1E-13 K = 3E-13 K = 1E-10 Paste Values
Yu, A. , et al., Physical Properties Measurement Program (U), WSRC-RP-93-894, Westinghouse Savannah River Company, Aiken, SC, USA, Attachment 1, Section 1, (referenced page p. 1-6).	Saturated E-Area Vault Concrete measured by Core Laboratories, TX for SRS. Saturated Z-Area Vault Concrete measured by Core Laboratories, TX for SRS.	K = 1E-12 (cm/s) to K = 7.4E-13 (cm/s) K = 2.3E-09 (cm/s) to K = 1.1E-10(cm/s)	K = 2.3E-09 to K = 7.4E-13 SRS Concrete Vault

Relationship Between Permeability and Hydraulic Conductivity

Hydraulic conductivity is the proportionality constant K_h (length/time) in the following expression of Darcy's Law:

$$q = -K_h \quad i \quad A$$

Where: q = flow rate (cm^3/sec)

i = hydraulic gradient (dimensionless)

$$i = \left(\frac{dp}{dx}\right)\left(\frac{1}{\rho g}\right)$$

A = total cross-sectional area of flow (cm^2)

K_h = hydraulic conductivity (cm/sec)

Coefficient of permeability is the proportionality constant K_p ($length^2$) and is an alternate expression of Darcy's Law:

$$q = -K_{ip}\left(\frac{\rho g \quad i \quad A}{\eta}\right)$$

Where: q = flow rate (cm^3/sec)

ρg = unit weight (g/cm^2sec^2)

i = hydraulic gradient (dimensionless)

A = total cross-sectional area of flow (cm^2)

η = fluid viscosity (g/cm sec = poise)

K_{ip} = intrinsic permeability (cm^2)

Permeability or Darcy permeability is the proportionality constant in a third form of Darcy's Law, commonly used for experimental determination of the relationship between flow rate and driving forces of a fluid through a porous medium:

$$q = \left(\frac{-K_p}{\eta}\right)\left(\frac{dp}{dx}\right)A$$

Where: q = flow rate (cm^3/sec)

η' = fluid viscosity (g/cm sec = poise)

p = pressure (atmosphere)

x = flow distance (cm)

A = total cross-sectional area of flow (cm^2)

K_p = permeability

References:

Basheer, P. A. M. 2001. "Permeation Analysis" in Handbook of Analytical Techniques in Concrete Science: Technology Principles, Techniques and Application, ed. Ramachandran, V. S. and Beaudoin, J. J., p. 658-737 (referenced page, p.704), Noyes Pub., NJ, USA, 2001. Information extracted from original reference: Hope, B. B. and Malhotra, V. M., "Measurement of Concrete Permeability," Canadian Journal of Civil Engineering, v. 11, p. 287-292 (1984).

Beaudoin, J. J., August 2005. Personal communication.

El-Dieb, A. S. and Hooton, R. D., 1994. "Evaluation of the Katz-Thompson Model for Estimating the Water Permeability of Cement-Based Materials from Mercury Intrusion Porosimetry Data," Cement and Concrete Research, v. 24, no. 3, p. 443-455 (p.450, 452).

Hearn, N. and Figg, J., 2001. "Transport Mechanisms and Damage: Current Issues in Permeation Characteristics of Concrete," Chapter in Materials Science of Concrete VI, ed. by Mindess, S. and Skalny, J., 2001, p. 327 – 375 (referenced page p. 358).

Hearn, N., Detwiler, R. J., and Sframeli, C., 1994. "Water Permeability and Microstructure of Three Old Concretes," Cement and Concrete Research, v. 24, no. 4, p. 633-640 (referenced page, p.635 and 637).

Hearn, N. 1990. "A Recording Permeameter for Measuring Time-Sensitive

Permeability of Concrete," Advances in Cementitious Materials *Ceramic Transactions*, v. 16,, ed. Mindess, S., p. 463-475 (referenced pages, p.467-471), American Ceramic Society, Westerville, OH.

Luping, T. and Nilsson, L., 1992. "A Study of the Quantitative Relationship Between Permeability and Pore Size Distribution of Hardened Cement Pastes," Cement and Concrete Research, v. 22, no. 4, p. 541 to 550, (referenced pages, P.545 to 547), July 1992.

Osborne, G. J., 1989. "Carbonation and Permeability of Blast Furnace Slag Cement Concretes from Field Structures," Am. Concrete Institute SP 114-59, in Proceedings of the Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, ed., Malhotra, V. M., Trondheim, Norway, v. 2, p. 1209-1237 (referenced pages, p.1233 and 1234).

Powers, T. C., Copeland, L. E., Hayes, J. C., and Mann, H. M., 1954/1955. Permeability of Portland Cement Paste, Portland Cement Association Bulletin 53, April 1955, Portland Cement Association, Skokie, IL, USA; reprinted from: J. of the American Concrete Institute, vol. 51, p. 285 to 298, Nov. 1954. (referenced page, p. 297).

Snyder, K. A., 2003. Condition Assessment of Concrete Nuclear Structures Considered for Entombment, NISTIR 7026, (referenced page, p.5), U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology, July 2003.

U.S. Department of the Interior,Water and Power Resources Service, 1981. Concrete Manual, 8th ed., U.S. Government Printing Office, Washington D.C., 1975 reprinted 1981, (referenced page, p. 37).

Walton, J. C., Planky, L. E., and Smith R. W., 1990. Models for Estimation of Service Life of Concrete Barriers in Low-Level Radioactive Waste Disposal, NUREG/CR-5543, EGG-2597; prepared for Div. of Eng., U.S. Nuclear Regulatory Commission, Washington D.C., Sept. 1990 (referenced page, p.4).

Yu, A. D., et al., Physical Properties Measurement Program, WSRC-RP-93-894, Westinghouse Savannah River Company, Savannah River Technology Center, Aiken SC. June 30, 1993. (referenced page Core Laboratory Attachment Section 1, p.1-6).

Action Item 6 (8/17/05): ***Uranium Inclusion in Sensitivity Analyses***

Include one isotope of uranium as a radionuclide considered in sensitivity analyses.

SRS Response: In the public meeting on August 17-18, 2005 between the U. S. Nuclear Regulatory Commission (NRC) and the U. S. Department of Energy (DOE), the NRC requested that in the sensitivity analyses, in particular sensitivity case 26, uranium be added to the list of radionuclides analyzed. It was agreed that U-238 would be added. It was also agreed that since the K_d of tritium could not be decreased below the base case value of 0 mL/g, that tritium would be removed from the list of radionuclides analyzed in sensitivity case 26. In addition, for other sensitivity cases that included uranium isotopes as radionuclides to be analyzed (sensitivity cases 29, 30 and 33) it was agreed that the analyses only need to include U-238 and not all the uranium isotopes. Results and analysis of the sensitivity cases are provided in the response to NRC Action Item 10 (8/17/05) contained within this document.

Action Item 7 (8/17/05): ***Flow through Cracks and Oxygen Sensitivity Analysis***

Provide results of sensitivity analysis for flow through cracks and 100% oxidation of the saltstone.

SRS Response: A sensitivity case that assumes saturation of the vault and saltstone was completed to assess the flow through cracks with oxidizing conditions. Results and analysis of the sensitivity case are provided in the response to U. S. Nuclear Regulatory Commission (NRC) Action Item 10 (8/17/05) contained within this document. The sensitivity case associated with these conditions is sensitivity case 32.

In scenario 32, the vault and Saltstone were assumed to exhibit large-scale cracking at a 30-foot nominal spacing. The cracks were assumed to be fully saturated by redefining the water retention and relative permeability curves, such that both are 1.0 regardless of the suction head. In addition, it is assumed that the vault and Saltstone have no reducing capacity (i.e., oxidizing K_d is used for Tc-99). This scenario assumes complete loss of reducing capacity of the vault and Saltstone at time zero.

A detailed discussion of the results from these sensitivity cases is included in the response to NRC Action Item 10 (8/17/05).

Action Item 8 (8/17/05): ***Minimizing Fill Pipe Impacts***

Information on why the impacts of the fill pipes' possible corrosion, expansion, and resultant cracking would be minimal.

SRS Response: The primary function of the roof on Vault #4 is to act as a weather shield, and thus prevent large volumes of standing water from collecting on top of the radioactive grout. Large volumes of standing water in the vault would adversely affect the curing of grout, and therefore are not permitted. The original vault design had a removable metal roof that covered only two of the twelve cells. This configuration limited vault operations to the two covered cells. The removable metal roof was replaced with the current concrete roof structure to provide operational flexibility.

Per the current operating philosophy, once a given vault cell is filled to the height of 24.75 feet, an additional 1.33 feet to 3.25 feet of clean grout will be poured in the cell to fill the void between the top of the grout and the bottom of the roof. This clean grout will be poured using the 50 individual three-inch fill pipes located on the roof of each cell. The pipes are evenly spaced across the roof, allowing complete coverage of the cell. Each pipe will be filled with grout and capped when the cell is closed.

The current SDF Closure Concept calls for the roof to remain in place and for the final closure cap to be installed over the top of the existing structure (WSRC 2005). The SDF Closure Concept places a geosynthetic clay liner directly on top of the roof, with a drainage layer located above the liner to minimize the moisture flux through the waste in the vault. With the current SDF Closure Concept, the concrete vault roof is credited with minimizing the flow of moisture through the waste after final closure activities are complete.

However, as discussed in the response to NRC Action Item 3 (8/17/05), the final design of the closure cap is still being developed. Once the design is complete and the actual design specifications are known, WSRC will evaluate the long-term effects of the penetrations in the vault roof on the overall vault performance. If it is determined that these penetrations provide an unacceptable moisture flow path after the carbon steel fixtures have undergone significant corrosion, the Closure Plan will be revised to include modifications to the roof penetrations, such as removal of the pipes and filling of the penetrations with non-shrink grout or encasement of the pipes within concrete, or modifications to the closure cap to remove additional moisture from the soil above the vault. The requirement to evaluate the effects of the vault roof penetrations on the long-term performance of the vault will be documented in the Closure Plan for the Z-Area Saltstone Disposal Facility.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-00074, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 9 (8/17/05): ***Relative Permeability Assumptions***

Provide information supporting assumptions of relative permeability.

SRS Response: The response to NRC Action Item 15 (7/27/05) addresses potential inaccuracies in the generated moisture characterization curves based on the Core Laboratory results (WSRC 2005; pages 223-226). Potentially, higher relative permeability conditions could exist for the Saltstone and the vault. The effect of potentially higher relative permeability on dose was assessed from the results of sensitivity case 13 described in the response to NRC RAI Comment 19 (WSRC 2005; p. 133-155). This case used the saturated conductivity value even under unsaturated conditions. Specifically, the scenario assumes that the relative permeability of Saltstone and concrete is 1.0 regardless of saturation/suction head. The result is a relatively minor increase in dose from 0.05 mrem/yr to 0.19 mrem/yr. For reference, the performance objective for the facility is a dose not exceeding 25 mrem/yr.

References:

WSRC, 2005, *Response to Request for Additional Information on the Draft Section 3116 Determination for Salt Waste Disposal at the Savannah River Site*, CBU-PIT-2005-00131, Revision. 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Action Item 10 (8/17/05): ***Sensitivity Analyses Results and Conclusions***

Provide interpretation and analysis of sensitivity analyses results and conclusions, including any resultant changes in the list of which radionuclides DOE considers to be highly radioactive (RAIs 19,11).

SRS Response:

On July 27 and August 17-18, 2005, staff and management from the U.S. Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) met to discuss DOE's responses to NRC's Request for Additional Information (RAI) regarding the draft waste determination for salt waste disposal at the Savannah River Site (SRS). As a result of these two meetings, additional Action Items were requested by the NRC to be provided by DOE. From the July 27, 2005 meeting, 22 Action Items were requested by the NRC to the DOE and from the meeting on August 17-18, 2005, 11 additional Action Items were requested by the NRC to the DOE. This response to NRC Action Item 10, from the August 17-18, 2005 meeting, is an integrated assessment of the sensitivity of all-pathways dose calculations to selected radionuclides and model parameters of the Saltstone Vault 4 Special Analysis (Cook et al. 2005). The objective of this response is to provide support to the conclusion that the Vault 4 Special Analysis provides reasonable assurance that the solidified salt waste can be disposed in Vault 4 and that all applicable performance measures, including the 25 mrem/year all-pathways public dose limit, will be met.

Requested Action Items from the July 27 and August 17-18, 2005 meetings that are associated with additional sensitivity analyses are as listed below.

From the 7/27/05 meeting:

Action Item 4 – Infiltration rates to the top of the vaults and sensitivity analysis evaluating combinations of parameters (RAI 19).

Action Item 7 – Basis for degraded values of concrete and saltstone grout beyond professional judgment (RAI 32).

Action Item 8 – Assessment of flow through fractures considering realistic conditions (e.g., seismically induced offset, variability in moisture, infilling of fractures) (RAI 36).

Action Item 9 – Any additional information to support reducing conditions of the Saltstone wasteform considering cracking and oxygen transport in the gas phase (RAI 41, 55).

Action Item 12 – Information on the range of precipitation and infiltration rates with regard to the cap (RAI 20).

Action Item 16 – Sensitivity analysis and/or model support for saturation of the vaults (RAI 35).

From the 8/17-18/05 meeting:

Action Item 4 – Provide bases for values used in the sensitivity analyses described in the handout.

Action Item 6 – Include one isotope of uranium as a radionuclide considered in sensitivity analyses.

Action Item 7 – Provide results of sensitivity analysis for flow through cracks and 100% oxidation of the saltstone grout.

Development of the Sensitivity Analyses

A total of 33 sensitivity analyses have been performed for the all-pathways dose calculations to selected radionuclides and model parameters for the Saltstone Vault 4 Special Analysis. The first sensitivity analysis was performed as the base case for the 2005 Special Analysis (SA). An additional 21 sensitivity analyses were performed for the DOE responses to the NRC's RAI's. From the July 27 and August 17-18, 2005 meetings, eleven additional sensitivity analyses were performed. All the sensitivity analyses are summarized in Table 10-1.

The eleven additional sensitivity scenarios were performed using PORFLOW (ACRi, Inc. 2005) to quantify the impact of key model parameter settings on groundwater contaminant concentrations and dose at the 100-meter compliance well through 10,000 years. The use of the 100-meter compliance well, while consistent with NRC's licensing practices, is a very conservative point of compliance given the location of the facility in the General Separations Area and the long-term stewardship requirements for the site. These additional scenarios explore the impacts of additional radionuclides and combinations of parameters beyond those considered in the response to NRC RAI 19. These additional scenarios, along with the original sensitivity scenarios documented in the response to NRC RAI 19, are summarized in Tables 10-2 and 10-3. The three technetium scenarios presented in the response to NRC RAI 19 are included and redesignated as scenarios 20, 21, and 22, respectively.

The key model parameters addressed in the additional sensitivity scenarios (i.e., scenarios 23 – 33) are:

- More pessimistic values for initial and final saturated hydraulic conductivity of the vault and saltstone grout
- Increased precipitation due to major climate change
- Lower distribution coefficients (K_d) and additional radionuclides (Sr-90, Cs-137, U-238, Np-237, Pu-238, and Pu-239)
- Impact of flow through cracks, and
- Combinations of these varied parameters.

Eleven New Sensitivity Scenarios

In scenario 23, the final saturated hydraulic conductivity of the degraded vault and saltstone grout was set to 1E-6 cm/second at 10,000 years, by increasing the degradation rate (i.e., the α parameter) to 3 for the vault and to 2.5 for saltstone grout. An additional radionuclide, Np-237, was included in the scenario. See response to NRC RAI 32 for discussion on concrete degradation.

In scenario 24, the average precipitation used in the Hydrologic Evaluation of Landfill Performance (HELP) code to calculate infiltration to the PORFLOW model domain was increased by 25% based on a hypothetical climate change. An additional radionuclide, Np-237, was included in the scenario. Attachment 1 to this response discusses the development of the 25% increase and the resulting infiltration. The beginning of Attachment 1 clearly shows, however, that potential changes in precipitation due to climate change in the Southeast are highly speculative and should not be taken as the base case.

In scenario 25, the increased precipitation (scenario 24) was combined with scenarios 5 and 9 in which the degradation rate of saltstone grout and the vault was increased to yield a final saturated hydraulic conductivity of 1E-8 cm/s (i.e., $\alpha_{vault} = 2.0$ and $\alpha_{Saltstone} = 1.5$). An additional radionuclide, Np-237, was included in the scenario.

In scenario 26, the distribution coefficient, K_d, for all radionuclides analyzed and in all media (e.g., saltstone grout, soil) was decreased by a factor of 10 from that used in the Vault 4 Special Analysis (Cook et al. 2005). Six radionuclides (i.e., Sr-90, Cs-137, U-238, Np-237, Pu-238, and Pu-239) were added.

In scenario 27, scenarios 9 and 11 were combined to assess the coupled effect of a higher initial saltstone grout saturated hydraulic conductivity (i.e., 1E-10 cm/sec) and an increased saltstone grout degradation rate (i.e., $\alpha_{Saltstone} = 1.5$). An additional radionuclide, Np-237, was included in the scenario.

In scenario 28, the initial saturated hydraulic conductivity of the vault was set at 1E-8 cm/s, which is two orders of magnitude greater than that used in scenario 11 and degraded to 1E-6 cm/s. An additional radionuclide, Np-237, was included in the scenario.

In scenario 29, the loss of the reducing property in saltstone grout and the vault was simulated by reducing the K_d for Tc-99 and U-238, the radionuclides affected by the change from reducing to oxidizing conditions. See responses to NRC RAI 41 and 55 for discussion on degradation of saltstone and reduction capacity of slag.

In scenario 30, scenarios 25 and 29-oxidized were combined to address the combined effects of oxidized saltstone grout and vault (i.e., no slag present from time equals zero), increased precipitation, and increased degradation of the vault and saltstone grout. See responses to NRC RAI 41 and 55 for discussion on degradation of saltstone and reduction capacity of slag.

In scenario 31, the vault and saltstone grout were assumed to exhibit large-scale cracking at a 30-foot nominal spacing. The cracks were assumed to be fully saturated by redefining the water retention and relative permeability curves, such that both are 1.0 regardless of the suction head. An additional radionuclide, Np-237, was included in the scenario.

Scenario 32 is the same as scenario 31, except that it was assumed that the vault and saltstone grout have no reducing capacity (i.e., oxidizing K_d is used for Tc-99, simulating no slag present from time equals zero).

In scenario 33, infiltration to the vault was set at 25 cm/yr throughout the simulation and the closure cap drains are silted to allow increased infiltration to go to the saltstone grout. The hydraulic conductivity of the vault and saltstone grout were set to 5E-7 cm/sec throughout the simulation. Effective diffusivity for the vault and saltstone grout was increased by a factor of 10 (i.e., to 1E-7 cm^2/sec for the vault and 5E-8 cm^2/sec for saltstone grout). The oxidation of saltstone grout was modeled as 0 and 100% (i.e., no slag present from time equals zero).

The predicted peak fractional fluxes to the water table and the peak concentrations of each radionuclide at the 100-m well are shown in Tables 10-4 through 10-14.

Sensitivity Results Expressed as Dose from All Pathways

The peak fractional concentrations from the PORFLOW model, and the projected radionuclide inventory for Vault 4 (see response to NRC RAI Comment 62) were used to calculate peak radionuclide concentrations over 10,000 years. The peak concentrations were input to the LADTAP program (Simpkins 2004) to calculate the all-pathways dose for each of the scenarios. Peak concentrations for each of the individual radionuclides do not occur simultaneously. However, for additional conservatism in the dose calculations, it was assumed that all radionuclides were at peak concentration. The resulting doses are shown in Table 10-15. The doses range from 0.02 mrem/year for scenario 2 (decreased infiltration due to continuous bamboo cover) to 34,000 mrem/year for scenario 33 (oxidizing) (greatly increased infiltration, greatly increased vault and saltstone grout hydraulic conductivity and diffusivity, and complete oxidation of the vault and saltstone grout at time zero as if no slag was present). The results of this analysis are intended to show the sensitivity of the system to changes in various parameters as opposed to actual dose comparisons against the all-pathways doses calculated in the *Saltstone Performance Objective Demonstration Document* (PODD) (Rosenberger et al. 2005). This sensitivity analysis was done using the projected Vault 4 radionuclide inventory (d'Entremont and Drumm 2005) whereas the all-pathways dose calculated in the PODD assumed the entire inventory of SRS salt waste radioactivity is contained in Vault 4. The results would not be expected to be significantly different relative to each other if the sensitivity analysis was to be run using the same radionuclide inventory used in the PODD. It should be noted that all of the waste from the Deliquification, Dissolution and Adjustment (DDA) step of salt processing is expected to be disposed of in Vault 4 and is reflected in the inventory used in both the base case and the sensitivity cases.

Since the dose results of the first 22 scenarios were discussed in the response to NRC RAI 19, the results of the new scenarios are discussed below. However, it should be noted that the dose in scenario 19 (set partition coefficients for C-14, Se-79, and I-129 to zero) is dominated by the dose from C-14. The nominal K_d (i.e., the value used in the Vault 4 Special Analysis) for C-14 in the vault and saltstone grout is 5,000. With the high pH and presence of calcium in the vault and saltstone grout, it is unrealistic to use a K_d of 0 for carbon.

Dose Results from the Eleven New Sensitivity Scenarios

In scenario 23, the use of an unrealistic final saturated conductivity for both the vault and saltstone grout of 1E-6 cm/sec at 10,000 years results in a dose of 16 mrem/year, which is an increase of about 320 times beyond the base case dose of 0.048 mrem/year. A saturated conductivity of 1E-6 cm/sec is analogous to a clayey-sand soil, which is two orders of magnitude greater than the upper range of standard concrete (i.e., 1E-08 cm/sec). See response to NRC Action Item 5 for discussion on hydraulic conductivity for the vaults. This illustrates that the sensitivity of the dose to saturated hydraulic conductivity is rather low because, even though the degradation rates for the vault and saltstone grout were increased unrealistically by a factor of one million for the vault and one-hundred thousand for saltstone grout over ten thousand years, the results of the calculated all-pathways dose only increased to 16 mrem/year.

The dose for scenario 24, in which the average precipitation was increased by 25% to assess the sensitivity to potential climate change, is 1.1 mrem/year, an increase by about 22 times above the base case. The beginning of Attachment 1 to this response clearly shows, however, that potential changes in precipitation due to climate change in the Southeast are highly speculative and should not be taken as the base case.

The dose for scenario 25 is 6.6 mrem/year, an increase from the base case of about 140 times. This illustrates the coupled effect of increased precipitation and increased degradation of the vault and saltstone grout. As discussed above for scenario 24, the 25% increase in precipitation due to climate change is highly speculative and should not be taken as the base case.

For scenario 26, in which the K_ds for all radionuclides in all media were arbitrarily reduced by a factor of 10, the dose increased by about 38 times to 1.8 mrem/year.

In scenario 27, where the pessimistic initial saltstone grout hydraulic conductivity used in scenario 11 (1E-10 cm/s, ten times higher than the base case of 1E-11) and the pessimistic saltstone grout degradation rate used in scenario 9 ($\alpha = 1.5$, resulting in a final saturated hydraulic conductivity of 1E-8 cm/s compared with the final saturated hydraulic conductivity of 1E-9 cm/s in the base case) were combined, the dose is 0.43 mrem/year. This is an increase in dose of a factor of 9.

In scenario 28, where a very pessimistic initial vault saturated hydraulic conductivity of 1E-8 cm/s (10,000 times higher than in the base case of 1E-12 cm/s) was assumed, the dose is 0.11 mrem/year, an increase of about a factor of two.

In scenario 29, where the loss of the reducing property in the vault and saltstone grout was simulated from time zero, the dose for oxidizing conditions is 3.2 mrem/year (i.e., the same as that for scenario 21) and the dose for reducing conditions is 1.6E-13 mrem/year (i.e., the same as that for scenario 20). These results show that the uranium isotopes contribute little to the dose, even under oxidizing conditions. Assuming loss of the reducing capacity of the vault and saltstone grout at time zero is unrealistic due to the presence of slag as an integral part of the construction materials in both the vault and saltstone grout matrix (see response to NRC Action Item 9 (7/27/05)).

In scenario 30, completely oxidizing saltstone grout and the vault from time zero was combined with increased precipitation and increased degradation of the vault and saltstone grout (i.e., a combination of scenarios 25 and 29-oxidized). The resulting dose is 1,200 mrem/year. Again, assuming complete loss of reducing capacity of the vault and saltstone grout at time zero is unrealistic given that slag is an integral part of the saltstone grout and vault and its demonstrated effectiveness in reducing technetium (see response to NRC Action Item 9 (7/27/05)).

In scenario 31, large-scale cracking of the vault and saltstone grout, coupled with the assumption that the vault, saltstone grout and cracks are fully saturated results in a dose of 3.5 mrem/year.

Scenario 32, which combined scenario 31 (i.e., saturated cracks) with completely oxidized saltstone grout and vault, gives a dose of 26 mrem/year. Again, assuming complete loss of reducing capacity of the vault and saltstone grout at time zero is unrealistic (see response to NRC Action Item 9 (7/27/05)).

In scenario 33, an unrealistic infiltration rate of 25 cm/year was assumed through the upper Geosynthetic Clay Liner (GCL) and the drains were assumed to be completely silted up throughout the simulation. This was coupled with a pessimistic value of 5E-7 cm/sec for the hydraulic conductivity of the vault and saltstone grout throughout the simulation and a factor of 10 increase in the effective diffusivity for the vault and saltstone grout. This was modeled for both reducing and oxidizing conditions. The resulting dose was 310 mrem/year for reducing conditions and 34,000 mrem/year for oxidizing conditions. Again, assuming complete loss of reducing capacity of the vault and saltstone grout at time zero is unrealistic given that slag is an integral part of the saltstone grout and vault and its demonstrated effectiveness in reducing technetium (see response to NRC Action Item 9 (7/27/05)). (NOTE: This scenario is not credible in that it represents a disposal system that has no closure cap and no vault and in which the saltstone grout had properties similar to SRS sandy clay soil).

The results of this comprehensive analysis will be used to support improvements to the Saltstone Performance Assessment, which will be started in FY06, and will include all the existing and future saltstone disposal vaults. Improvements will include enhanced modeling of the physical and chemical properties of saltstone grout and the saltstone disposal vault system emphasizing the initial and degraded hydraulic properties of the system. In addition, changing oxidation-reduction conditions of the waste disposal system over time will be explicitly modeled. Also, a probabilistic uncertainty analysis will be conducted. These and other enhancements to improve the Saltstone Performance Assessment are part of the Performance Assessment Maintenance Program, which is reviewed and updated annually.

Dose Results for Selected Radionuclides

Of the eleven radionuclides listed in Table 10-15 of this Action Item for the 33 sensitivity scenarios, five radionuclides had all-pathway doses sufficient to warrant discussion (i.e., dose exceeded ten percent, 2.5 mrem/yr, of the all-pathways performance objective of 25 mrem/yr.). The five radionuclides are H-3, C-14, Se-79, Tc-99, and I-129.

Tritium (H-3) exceeded 2.5 mrem/yr in scenario 33, where the infiltration rate through the Upper Geosynthetic Liner (GCL) was arbitrarily set at 25 cm/year, coupled with a hydraulic conductivity of the vault and saltstone grout set at 5E-7 cm/sec, and the effective diffusivity for the vault and saltstone grout increased by a factor of 10. As discussed above, Scenario 33 is not considered a credible scenario. This scenario was modeled for both an oxidized and reduced condition, resulting in the same dose. This indicates that tritium is not sensitive to the oxidation or reduction conditions.

C-14 exceeded 2.5 mrem/yr only in scenario 19, where the distribution coefficient (K_d) was set at zero. The nominal K_d (i.e., the value used in the Vault 4 Special Analysis) for C-14 in the vault and saltstone grout is 5,000. With the high pH and presence of calcium in the vault and saltstone grout, it is unrealistic to use a K_d of 0 for carbon.

Se-79 exceeded 2.5 mrem/yr in scenarios 19, 23, 31, 32 and 33. In scenario 19, as discussed above for C-14, the K_d value for Se-79 was set to zero, which is unrealistic.

Se-79 exceeded 2.5 mrem/yr in scenario 23 where the unrealistic value of 1E-06 cm/sec was used for the final saturated conductivity for both the vault and the saltstone grout. This is analogous to a clayey-sand soil, which is two orders of magnitude greater than the upper range of standard concrete (i.e., 1E-08 cm/sec). Se-79 also exceeded 2.5 mrem/yr in scenarios 31 and 32 where large-scale cracking of the vault and saltstone grout occurred in conjunction with the full saturation of the vault, saltstone grout and the cracks. Due to Se-79 having a relatively low K_d value of 0.1, saturated, large-scale cracks would naturally allow the Se-79 to migrate along with the infiltrating water passing through the large-scale cracks. Lastly, Se-79 exceeded 2.5 mrem/yr in scenario 33 which, as discussed above, is not a credible scenario. Similar to the tritium (H-3) in this scenario (see discussion for tritium above), Se-79 was not sensitive to the oxidation or reduction conditions.

Tc-99 exceeded 2.5 mrem/yr in several scenarios, including scenarios 21, 22, 29, 30, 32 and 33. All of these above listed scenarios have the saltstone grout and vault in an oxidized state starting at time zero, which ignores the reducing capacity of the slag, which is an integral part of both the vault and saltstone grout. Therefore, these are unrealistic scenarios since the slag has been demonstrated to keep the saltstone grout and vault in a reducing condition (see response to NRC Action Item 9 (7/27/05)). Tc-99 is much more mobile in an oxidizing condition, and that explains why there is such a large difference in the dose rate for scenario 33 oxidized verses reduced. As discussed previously, scenario 33 is not credible in that it represents a disposal system that has no closure cap and no vault and in which the saltstone grout had properties similar to SRS sandy clay soil.

I-129 exceeded 2.5 mrem/yr in several scenarios, including scenarios 12, 23, 25, and 33. In all cases, either the infiltration rate through the Geosynthetic Clay Liner (GCL) increased (in scenario 12 the infiltration rate was arbitrarily increased, in scenario 23 the increase was due to increased precipitation), or an unrealistic value for the hydraulic conductivity of the vault and saltstone grout was used. With the relatively low K_d value for I-129 (2E+00 cm^3/g), it is expected that under these unrealistic conditions, that the all-pathway dose would increase. For scenario 33, I-129 had the same dose for the oxidized condition as it did for the reduced condition, indicating that it is not sensitive to the oxidation or reduction conditions.

Analysis of Sensitivity Results

To assist in interpreting the results of the sensitivity study, a measure called the normalized sensitivity (Meyer and Taira 2001) was used. Equation 3-2 of this reference is:

$$S_n = \frac{x_a}{D_a} \cdot \frac{\delta D}{\delta x}$$

S_n is the normalized sensitivity, x_a and D_a are the nominal values of the parameter in question and the peak dose and δ D and δ x are the changes in dose and the parameter, respectively, in each sensitivity case. Using the normalized sensitivity measure eliminates the effects of units and the absolute magnitude of each parameter. The absolute value of S_n is a measure of the importance of the parameter or parameters to the calculated dose for each case (i.e., the parameters being most important to calculated dose).

Table 10-16 gives the results and the value of S_n for each of the sensitivity cases. Cases 13, 19, 26, 31 and 32 evaluated a fundamentally different approach than that used in the 2005 Special Analysis (Cook et al. 2005) (e.g., relative permeability always set to 1, all partition coefficients set to zero mL/g), and thus could not be evaluated using this approach.

The cases having the five greatest absolute values for the normalized sensitivity are 33 Oxidizing (-710,000), 30 (-76,000), 33-Reducing (2100), 22 (-1900) and 25 (550). Of these five case, four (33-Oxidizing, 30, 33-Reducing and 25) involve an increase in precipitation or infiltration and three (33-Oxidizing, 30 and 22) involve the lack of reducing capacity in the disposal system, which is characterized by a low value of the partition coefficient for technetium.

The five cases involving a change in only one parameter with the greatest normalized sensitivity are 22 (-1900), 24 (88), 21 (67), 3 (9.3) and 2 (1.2). Each of these deals either with infiltration or the partition coefficient of technetium.

The conclusion of this analysis is that the calculated dose from the Saltstone disposal system is most sensitive to the oxidation state of the system, which determines the partition coefficient for technetium, and the amount of precipitation, which determines the infiltration rate of water reaching the disposal system. The actual state of the system with respect to these parameters is determined by the design and implementation of the final cover and the materials used to construct the disposal vault and create the Saltstone waste form.

The study shows that the calculated dose is far less sensitive to the values used for initial saturated hydraulic conductivity of the vault and saltstone grout, and the degradation rates of those materials than to precipitation and oxidation state.

Conclusions

The results of the sensitivity analyses show that the projected dose from disposal of saltstone grout at the Savannah River Site is most dependent on the amount of precipitation and resultant infiltration of water through the saltstone grout and the oxidation-reduction condition of the vault and saltstone grout. As shown in several of the responses to NRC RAI Comments and Action Items, these parameters are ones that SRS has a high degree of confidence will perform as described in the Special Analysis.

Specifically, the response to NRC RAI 41 showed that, after 10,000 years, only 3% of the reducing capacity would be lost, assuming there were no cracks in the saltstone grout or vault. The response to NRC Action Item 9 (7/27/05) confirmed the high reducing capacity of slag in the saltstone grout and vault formulations, and showed through the results of field lysimeter experiments that technetium was not released from slag saltstone. This response also showed that, in waste tank closure modeling, only 5% of the reducing capacity was consumed over 10,000 years assuming one concentric crack and only 8% was consumed assuming three concentric cracks. These simulations dealing with the waste tank are applicable to the Saltstone Disposal Facility because they use the same slag material, have a cementitous environment, and the movement of water (the vector transporting the dissolved oxygen that consumes the reduction capacity of the slag) will be controlled by diffusion (the process whereby molecules of dissolved oxygen move under the influence of their kinetic activity in the direction of their concentration gradient). As discussed previously, one of the planned improvements to the Saltstone Performance Assessment is that changing oxidation-reduction conditions of the waste disposal system over time will be explicitly modeled.

The responses to NRC Action Item 3 (8/17/05) and RAIs 20 and 28 show that the closure cap, which regulates the amount of water infiltrating the disposal system, is designed to be consistent with NRC guidance and to be physically stable over 10,000 years. Even with the bounding 25% increase in the precipitation rate, the closure cap is still effective in controlling erosion and, even though the increased precipitation leads to an increase in degradation (i.e., silting of drains), the resulting dose is acceptable.

The sensitivity of the calculated dose to parameters which have a greater degree of uncertainty, the hydraulic properties of the vault and saltstone grout and their rates of degradation, is much less, indicating that these parameter values can vary over a wide range and the system will still perform satisfactorily. The sensitivity analysis results also illustrate that model parameters can be manipulated to give doses that exceed the 25 mrem/year performance measure. However, every scenario that produced a dose higher than 25 mrem/year involved an unrealistic assumption. Specifically, all but one exceeding scenario unrealistically assumed that either the disposal system was in an oxidized state from time zero or that the cover system failed at time zero, or both. Furthermore, the one other exceeding scenario (scenario 19), set all K_ds to zero, which is physically and chemically unrealistic for C-14, the major contributor to the dose (32 mrem/year of the total 36 mrem/yr calculated in the scenario) in the vault environment. Thus, all exceeding scenarios, while important to understanding model sensitivities, do not approximate conditions that will actually occur.

These results, taken together with the Vault 4 Special Analysis, demonstrate that the saltstone disposal system is very robust in that the parameters which are hardest to measure or predict have relatively little impact on the calculated dose.

The Vault 4 Special Analysis and the results of these sensitivity studies clearly demonstrate that the solidified salt waste from the projected waste stream for Vault 4 can be disposed in Vault 4 and that all applicable performance measures, including the 25 mrem/year all-pathways public dose limit, will be met. The Vault 4 Special Analysis therefore, provides the basis for all other work (e.g., Waste Acceptance Criteria) involving predictions of long-term performance of Vault 4 as the disposal unit for the solidified salt waste.

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Table 10-1. Sensitivity Scenarios Analyzed

Run	Sensitivity Cases Description	Variables Altered	Discussion
1	2005 Special Analysis Base Case	N/A – Base Case	N/A – Base Case
2	Optimistic Cover Degradation	Peak Infiltration from 14 in/year to 7 in/year.	Addresses sensitivity of varying cap degradation
3	Pessimistic Cover Degradation	Peak Infiltration from 14 in/year to 21 in/year.	
4	Optimistic Vault Degradation	Saturated hydraulic conductivity of the vault goes from 1E-12 to 1E-10 cm/sec over 10,000 years.	Addresses sensitivity of varying vault degradation behavior
5	Pessimistic Vault Degradation	Saturated hydraulic conductivity of the vault goes from 1E-12 to 1E-8 cm/sec over 10,000 years.	
6	Optimistic Initial Vault Conductivity	Initial saturated hydraulic conductivity of the vault set at 1E-13 cm/sec	Addresses sensitivity of initial vault saturated hydraulic conductivity.
7	Pessimistic Initial Vault Conductivity	Initial saturated hydraulic conductivity of the vault set at 1E-11 cm/sec	
8	Optimistic Saltstone Grout Degradation	Saturated hydraulic conductivity of saltstone grout goes from 1E-11 to 1E-10 cm/sec	Addresses sensitivity to saltstone grout degradation rate
9	Pessimistic Saltstone Grout Degradation	Saturated hydraulic conductivity of saltstone grout goes from 1E-11 to 1E-8 cm/sec over 10,000 years.	
10	Optimistic Initial Saltstone Grout Conductivity	Initial saturated hydraulic conductivity of saltstone grout set at 1E-12 cm/sec	Addresses sensitivity to initial saltstone grout saturated hydraulic conductivity
11	Pessimistic Initial Saltstone Grout Conductivity	Initial saturated hydraulic conductivity of saltstone grout set at 1E-10 cm/sec	
12	Pessimistic Cover Degradation and Pessimistic Vault and Saltstone Grout Degradation – Combination of Runs 3, 5 and 9	Peak Infiltration from 14 in/year to 21 in/year. Saturated hydraulic conductivity of the vault goes from 1E-12 to 1E-8 cm/sec over 10,000 years. Saturated hydraulic conductivity of saltstone grout goes from 1E-11 to 1E-8 cm/sec over 10,000 years.	Addresses combined effect of pessimistic cover degradation, pessimistic vault and saltstone grout conductivity.
13	Vault and Saltstone Grout Saturated for Entire Run	Relative hydraulic conductivity set to 1 for both the vault and saltstone grout.	Addresses impact of saturation
14	Optimistic Vault Diffusion	Vault diffusion coefficient set to 1E-9 cm^2/sec	Assesses sensitivity to vault diffusion coefficient
15	Pessimistic Vault Diffusion	Vault diffusion coefficient set to 1E-7 cm^2/sec	
16	Optimistic Saltstone Grout Diffusion	Saltstone diffusion coefficient set to 5E-10 cm^2/sec	Assesses sensitivity to Saltstone diffusion coefficient

Run	Sensitivity Cases Description	Variables Altered	Discussion
17	Pessimistic Saltstone Grout Diffusion	saltstone grout diffusion coefficient set to 5E-8 cm^2/sec	
18	Pessimistic Vault and Saltstone Grout Diffusion – Combination of Runs 15 and 17	Vault diffusion coefficient set to 1E-7 cm^2/sec Saltstone grout diffusion coefficient set to 5E-8 cm^2/sec	Assesses sensitivity to combined vault and saltstone grout diffusion coefficient
19	Pessimistic Partition Coefficients	Partition coefficients for C-14, Se-79 and I-129 set to 0 mL/g	Assesses sensitivity to K_d
20	Reducing Conditions in Vault at all times	Technetium Partition Coefficient set to 1000 mL/g.	N/A – Base Case for technetium
21	Oxidizing Conditions in Vault at all times	Technetium partition coefficient set to 1 mL/g.	Assesses sensitivity to redox state of vault and saltstone grout
22	Oxidizing Conditions in Vault at all times with pessimistic technetium behavior	Technetium partition coefficient set to 0 mL/g.	Assesses sensitivity to redox state of vault and saltstone grout, using pessimistic technetium partition coefficient.

New Cases

Run	Sensitivity Cases Description	Variables Altered	Discussion
23	RAI# 32. Increase the final saturated hydraulic conductivity of degraded vault and saltstone grout to 1E-6 cm/sec at 10,000 years	Concrete K_s increases from 10^{-12} to 10^{-6} cm/s with a degradation rate constant, α = 3 Saltstone grout K_s increases from 10^{-11} to 10^{-6} cm/s with a degradation rate constant, α = 2.5 Degradation Equation: $\log_{10}\left(k/k_o\right) = \alpha \log_{10}\left(t/t_o\right)$ where k = saturated hydraulic conductivity at time t, cm/s; k_o = saturated hydraulic conductivity at t_o = 100 years, cm/s Radionuclides Analyzed: H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	A saturated hydraulic conductivity of 1E-6 cm/s is two orders of magnitude greater than the upper range of standard concrete (i.e., 1E-8 cm/s (Ramachandran and Beaudoin 2001)) and within the range of soil saturated hydraulic conductivities at SRS. Addresses more pessimistic values for saturated hydraulic conductivity of the vault and saltstone grout final degraded state.

New Cases

Run	Sensitivity Cases Description	Variables Altered	Discussion
24	RAI# 20. Increase precipitation and assess consequent increased infiltration.	Increase the average precipitation utilized within the base case (i.e., 48.9 in/yr) by 25%. Radionuclides Analyzed: H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	In a publication of the U.S. Global Change Research Program (The Potential Consequences of Climate Variability and Change Overview Southeast (www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewsoutheast.htm)), results from the two principal models used to assess climate change, due to CO_2 induced global warming, show increases in annual precipitation of no more than 25% across the Southeast U.S through year 2100. Further a report from the Intergovenrmental Panel on Climate Change (Climate Change 2001: Synthesis Report (www.ipcc.ch/pub/un/syreng/spm.pdf)), project that atmospheric CO_2 levels and hence, average temperature, will stabilize over the 22nd century. Addresses an increased average precipitation to explore the potential effect of climate change on the infiltration through the closure cap.
25	RAI# 19. Combine increased precipitation with pessimistic vault and saltstone grout degradation	Sensitivity cases 5, 9, and 24 are combined. Cases 5 and 9 increase the final saturated hydraulic conductivity of the degraded vault and saltstone grout at year 10,000 to 1E-8 cm/s. Case 24 increased the average precipitation by 25%. Radionuclides Analyzed: H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	A saturated hydraulic conductivity of 1E-8 cm/s is at the upper range of concrete saturated hydraulic conductivity (Ramachandran and Beaudoin 2001). See case 24 for a discussion of the rationale for a 25% increase in average precipitation. Addresses the coupled effect of increased infiltration and increased degradation of the vault and saltstone grout.
26	RAI# 19. Decrease K_ds in all media by 10x and add additional radionuclides.	The K_ds for the radionuclides in all media are reduced by a factor of 10 from the values presented in Table A-8 of Cook et al. 2005. Radionuclides Analyzed: C-14, Se-79, Sr-90, Tc-99, I-129, Cs-137, U-238, Np-237, Pu-238 and Pu-239.	Additional strongly sorbed radionuclides have been added to the analysis. These radionuclides represent the most abundant, strongly sorbed radionuclides with both short and long half-lives and those with a high dose conversion factor. Addresses the impact of increased radionuclide mobility.
27	RAI# 19. Combine pessimistic initial saltstone grout conductivity and pessimistic saltstone grout degradation.	Sensitivity cases 9 and 11 are combined. Saltstone grout K_s decreases from 10^{-10} to 10^{-7} cm/s with a degradation rate constant, $\alpha = 1.5$ Degradation Equation: $\log_{10}(k/k_o) = \alpha \log_{10}(t/t_o)$ where k = saturated hydraulic conductivity at time t, cm/s; k_o = saturated hydraulic conductivity at t_o = 100 years, cm/s Radionuclides Analyzed: H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	Addresses the coupled effect of a higher initial saltstone grout saturated hydraulic conductivity and an increased saltstone grout degradation rate.

New Cases

Run	Sensitivity Cases Description	Variables Altered	Discussion
28	RAI# 19. Pessimistic initial vault saturated hydraulic conductivity of 1E-8 cm/s.	Concrete K_s decreases from 10^{-8} to 10^{-6} cm/s with a degradation rate constant, α = 1.0 Degradation Equation: $\log_{10}(k/k_o) = \alpha \log_{10}(t/t_o)$ where k = saturated hydraulic conductivity at time t, cm/s; k_o = saturated hydraulic conductivity at t_o = 100 years, cm/s Radionuclides Analyzed: H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	A saturated hydraulic conductivity of 1E-8 cm/s is at the upper range of concrete saturated hydraulic conductivity (Ramachandran and Beaudoin 2001). This assesses a higher initial vault saturated hydraulic conductivity.
29	RAI# 19, 41, and 55. Simulate loss of reducing property in saltstone grout and vault by reducing the K_d for those radionuclides affected by the change from reducing to oxidizing conditions.	The following two ends in the oxidation/reduction continuum in the saltstone grout and vault are analyzed: Oxidizing K_ds for Tc-99 and the uranium isotopes taken from Bradbury and Sarott (1995). Reducing K_ds for Tc-99 and the uranium isotopes taken from Bradbury and Sarott (1995). Radionuclides analyzed: Tc-99 and U-238	Radionuclides whose K_ds are redox sensitive are considered. This includes the uranium isotopes (U-232, U-233, U-234, U-235, U-236, and U-238) in addition to Tc-99 (by agreement with the NRC, only U-238 was analyzed in addition to Tc-99). The response to NRC RAI Comment #41 showed a 3 percent reduction in reducing potential after 10,000 years. A subsequent analysis showed a 5 percent reduction in reducing potential after 10,000 years with the presence of cracks due to seismic activity. This assesses both complete oxidation and complete reduction.
30	RAI# 19, 41, and 55. Combine oxidizing saltstone grout & vault with increased infiltration and pessimistic vault and saltstone grout degradation.	Sensitivity cases 25 and 29-oxidized are combined (increased degradation of the vault and saltstone grout, increased infiltration, and oxidized condition of saltstone grout and vault). Radionuclides Analyzed: Tc-99, U-238	See cases 25 and 29 for a discussion of the rationale. Addresses the combined effects of oxidized saltstone grout and vault, increased infiltration, and increased degradation of the vault and saltstone grout.
31	RAI# 19. Assume saturation of the vault and saltstone grout to assess flow through cracks.	Assume vault and saltstone grout exhibit large-scale cracking at a 30 ft nominal spacing. Assume vault, saltstone grout and cracks are fully saturated. Implemented by redefining the water retention and relative permeability curves, such that both are 1.0 regardless of suction head. Radionuclides Analyzed: H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	The cracking is based upon modeling of potential impacts from large-scale seismic events and differential settlement as documented within Peregoy 2003. Cracks become active in the radionuclide transport process if they are completely water saturated. Addresses the effect of flow through cracks if the vault and saltstone grout were to be saturated in the first 10,000 years.

New Cases

Run	Sensitivity Cases Description	Variables Altered	Discussion
32	RAI# 19. Assume saturation of the vault and saltstone grout to assess flow through cracks with oxidizing conditions	Assume vault and saltstone grout exhibit large-scale cracking at a 30 ft nominal spacing. Assume vault, saltstone grout and cracks are fully saturated. Implemented by redefining the water retention and relative permeability curves, such that both are 1.0 regardless of suction head. Oxidizing K_ds used for Tc-99 Radionuclides Analyzed: : H-3, C-14, Se-79, Tc-99, I-129 and Np-237.	The cracking is based upon modeling of potential impacts from large-scale seismic events and differential settlement as documented within Peregoy 2003. Cracks become active in the radionuclide transport process if they are completely water saturated. Addresses the effect of flow through cracks if the vault and saltstone grout were to be saturated in the first 10,000 years in combination with oxidized conditions.
33	RAI# 19. Assumes greatly increased infiltration, hydraulic conductivity and diffusivity (vault and saltstone grout), and oxidation.	Infiltration to the vault is 25 cm/yr throughout the simulation and the closure cap drains silted to allow infiltration to go to saltstone grout. Hydraulic Conductivity of Vault and Saltstone Grout are set to 5E-7 cm/sec throughout the simulation. Effective diffusivity for the Vault and Saltstone Grout are increased by a factor of 10. Vault will be 1E-7 cm^2/sec (vs 1E-8 in base case) and Saltstone Grout 5E-8cm^2/sec (vs 5E-9 in base case). Modeled oxidation of Saltstone Grout as 0 and 100%. Radionuclides Analyzed: Tc-99, Np-237, U-238, H-3, C-14, Se-79, and I-129.	The NRC requested this sensitivity case to consider a very degraded state throughout the simulation (closure cap, vault, saltstone grout, oxidation) that combines a number of variables.

Table 10-2. Sensitivity scenarios and settings for infiltration, vadose zone concrete and Saltstone hydraulic conductivity.

Scenario Run	Sensitivity Settings		
	Infiltration	**Vadose Zone Concrete Hydraulic Conductivity**	**Vadose Zone Saltstone Hydraulic Conductivity**
1	Institutional Control (IC) to Pine Forest	Nominal	Nominal
2	Continuous Bamboo Cover	Nominal	Nominal
3	IC to Farm to Pine Forest	Nominal	Nominal
4	IC to Pine Forest	$\alpha = 1.0$	Nominal
5	IC to Pine Forest	$\alpha = 2.0$	Nominal
6	IC to Pine Forest	$0.1\times$Ksat	Nominal
7	IC to Pine Forest	$10\times$Ksat	Nominal
8	IC to Pine Forest	Nominal	$\alpha = 0.5$
9	IC to Pine Forest	Nominal	$\alpha = 1.5$
10	IC to Pine Forest	Nominal	$0.1\times$Ksat
11	IC to Pine Forest	Nominal	$10\times$Ksat
12	IC to Farm to Pine Forest	$\alpha = 2.0$	$\alpha = 1.5$
13	IC to Pine Forest	$k_r = 1$	$k_r = 1$
14	IC to Pine Forest	Nominal	Nominal
15	IC to Pine Forest	Nominal	Nominal
16	IC to Pine Forest	Nominal	Nominal
17	IC to Pine Forest	Nominal	Nominal
18	IC to Pine Forest	Nominal	Nominal
19	IC to Pine Forest	Nominal	Nominal
20	IC to Pine Forest	Nominal	Nominal
21	IC to Pine Forest	Nominal	Nominal
22	IC to Pine Forest	Nominal	Nominal
23	IC to Pine Forest	10^{-12} to 10^{-6} cm/s $\alpha = 3.0$	10^{-11} to 10^{-6} cm/s $\alpha = 2.5$
24	IC to Pine Forest + 25% Precipitation	Nominal	Nominal
25	IC to Pine Forest + 25% Precipitation	$\alpha = 2.0$	$\alpha = 1.5$
26	IC to Pine Forest	Nominal	Nominal
27	IC to Pine Forest	Nominal	10^{-10} to 10^{-7} cm/s $\alpha = 1.5$
28	IC to Pine Forest	10^{-8} to 10^{-6} cm/s	Nominal
29	IC to Pine Forest	Nominal	Nominal
30	IC to Pine Forest + 25% Precipitation	$\alpha = 2.0$	$\alpha = 1.5$
31	IC to Pine Forest	$k_r = 1$; cracking	$k_r = 1$; cracking
32	IC to Pine Forest	$k_r = 1$; cracking	$k_r = 1$; cracking
33	25 cm/yr	$5\text{x}10^{-7}$ cm/s	$5\text{x}10^{-7}$ cm/s

Table 10-3. Sensitivity scenarios and settings for distribution coefficient, vadose zone concrete and Saltstone molecular diffusion coefficient.

Scenario Run	Sensitivity Settings		
	Distribution Coefficient	**Vadose Zone Concrete Diffusion Coefficient**	**Vadose Zone Saltstone Diffusion Coefficient**
1	Nominal	Nominal	Nominal
2	Nominal	Nominal	Nominal
3	Nominal	Nominal	Nominal
4	Nominal	Nominal	Nominal
5	Nominal	Nominal	Nominal
6	Nominal	Nominal	Nominal
7	Nominal	Nominal	Nominal
8	Nominal	Nominal	Nominal
9	Nominal	Nominal	Nominal
10	Nominal	Nominal	Nominal
11	Nominal	Nominal	Nominal
12	Nominal	Nominal	Nominal
13	Nominal	Nominal	Nominal
14	Nominal	$0.1 \times D_M$	Nominal
15	Nominal	$10 \times D_M$	Nominal
16	Nominal	Nominal	$0.1 \times D_M$
17	Nominal	Nominal	$10 \times D_M$
18	Nominal	$10 \times D_M$	$10 \times D_M$
19	$k_d = 0$	Nominal	Nominal
20	Nominal	Nominal	Nominal
21	$K_d = 1$	Nominal	Nominal
22	$K_d = 0$	Nominal	Nominal
23	Nominal	Nominal	Nominal
24	Nominal	Nominal	Nominal
25	Nominal	Nominal	Nominal
26	$0.1*K_d$	Nominal	Nominal
27	Nominal	Nominal	Nominal
28	Nominal	Nominal	Nominal
29	Oxidized & Reduced	Nominal	Nominal
30	Oxidized	Nominal	Nominal
31	Nominal	Nominal	Nominal
32	Oxidized	Nominal	Nominal
33	Oxidized & Reduced	$10 \times D_M$	$10 \times D_M$

Table 10-4. H-3 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	4.03E-13	1.20E+02	1.11E-08	1.25E+02
2	1.26E-14	1.52E+02	3.56E-10	1.56E+02
3	7.75E-15	1.69E+02	2.18E-10	1.74E+02
4	3.96E-13	1.20E+02	1.07E-08	1.25E+02
5	3.96E-13	1.20E+02	1.07E-08	1.25E+02
6	3.96E-13	1.20E+02	1.07E-08	1.25E+02
7	3.95E-13	1.20E+02	1.07E-08	1.25E+02
8	3.96E-13	1.20E+02	1.07E-08	1.25E+02
9	3.96E-13	1.20E+02	1.07E-08	1.25E+02
10	3.96E-13	1.20E+02	1.07E-08	1.25E+02
11	3.97E-13	1.20E+02	1.07E-08	1.25E+02
12	7.68E-15	1.70E+02	2.16E-10	1.75E+02
13	3.95E-13	1.20E+02	1.07E-08	1.25E+02
14	3.96E-13	1.20E+02	1.06E-08	1.25E+02
15	8.53E-10	1.18E+02	2.28E-05	1.23E+02
16	8.06E-14	1.20E+02	2.16E-09	1.25E+02
17	6.52E-13	1.20E+02	1.75E-08	1.25E+02
18	2.95E-09	1.18E+02	7.90E-05	1.23E+02
19	4.03E-13	1.20E+02	1.11E-08	1.25E+02
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	4.00E-13	1.20E+02	1.11E-08	1.25E+02
24	1.31E-12	1.09E+02	3.48E-08	1.13E+02
25	1.31E-12	1.09E+02	3.48E-08	1.13E+02
26	4.00E-13	1.20E+02	1.11E-08	1.25E+02
27	4.00E-13	1.20E+02	1.11E-08	1.25E+02
28	3.70E-13	1.20E+02	1.02E-08	1.24E+02
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	5.57E-09	1.42E+02	1.56E-04	1.47E+02
32	5.57E-09	1.42E+02	1.56E-04	1.47E+02
33	1.58E-02	2.00E+01	4.33E+02	2.47E+01

Table 10-5. C-14 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	3.44E-24	1.00E+04	1.18E-19	1.00E+04
2	1.06E-25	1.00E+04	3.69E-21	1.00E+04
3	7.37E-23	1.00E+04	2.48E-18	1.00E+04
4	1.00E-25	1.00E+04	3.50E-21	1.00E+04
5	1.12E-20	1.00E+04	3.83E-16	1.00E+04
6	1.00E-25	1.00E+04	3.51E-21	1.00E+04
7	1.42E-20	1.00E+04	4.88E-16	1.00E+04
8	6.18E-25	1.00E+04	2.13E-20	1.00E+04
9	1.24E-22	1.00E+04	4.17E-18	1.00E+04
10	5.78E-25	1.00E+04	1.99E-20	1.00E+04
11	1.35E-22	1.00E+04	4.56E-18	1.00E+04
12	7.31E-18	1.00E+04	2.44E-13	1.00E+04
13	6.02E-23	1.00E+04	2.05E-18	1.00E+04
14	2.67E-24	1.00E+04	9.09E-20	1.00E+04
15	1.91E-21	1.00E+04	6.67E-17	1.00E+04
16	2.74E-24	1.00E+04	9.34E-20	1.00E+04
17	4.37E-24	1.00E+04	1.50E-19	1.00E+04
18	9.97E-21	1.00E+04	3.49E-16	1.00E+04
19	1.29E-05	6.99E+03	4.64E-01	7.00E+03
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	1.89E-10	1.00E+04	6.13E-07	1.00E+04
24	4.62E-21	1.00E+04	1.56E-16	1.00E+04
25	3.82E-16	1.00E+04	1.29E-11	1.00E+04
26	5.33E-19	1.00E+04	1.91E-14	1.00E+04
27	7.39E-22	1.00E+04	2.48E-17	1.00E+04
28	3.98E-13	1.00E+04	1.39E-08	1.00E+04
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	1.40E-09	4.44E+02	4.55E-05	5.23E+02
32	1.40E-09	4.44E+02	4.55E-05	5.23E+02
33	2.11E-08	1.00E+04	7.45E-04	1.00E+04

Table 10-6. Se-79 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	7.11E-07	1.00E+04	1.83E-02	1.00E+04
2	2.46E-07	1.00E+04	7.92E-03	1.00E+04
3	2.90E-06	1.00E+04	7.33E-02	1.00E+04
4	4.07E-07	1.00E+04	1.24E-02	1.00E+04
5	6.16E-07	1.00E+04	1.95E-02	1.00E+04
6	4.07E-07	1.00E+04	1.26E-02	1.00E+04
7	6.13E-07	1.00E+04	1.93E-02	1.00E+04
8	4.60E-07	1.00E+04	1.48E-02	1.00E+04
9	2.12E-06	1.00E+04	4.84E-02	1.00E+04
10	4.61E-07	1.00E+04	1.49E-02	1.00E+04
11	2.16E-06	1.00E+04	4.99E-02	1.00E+04
12	1.64E-05	1.00E+04	3.96E-01	1.00E+04
13	1.88E-06	1.00E+04	4.52E-02	1.00E+04
14	5.70E-07	1.00E+04	1.31E-02	1.00E+04
15	1.64E-06	1.80E+03	5.61E-02	3.52E+03
16	6.21E-07	1.00E+04	1.49E-02	1.00E+04
17	8.89E-07	1.00E+04	2.41E-02	1.00E+04
18	6.90E-06	3.68E+03	2.44E-01	4.79E+03
19	3.22E-05	9.70E+03	1.16E+00	9.71E+03
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	3.61E-04	8.73E+03	1.08E+00	1.00E+04
24	8.94E-06	7.02E+03	3.11E-01	8.61E+03
25	2.72E-05	6.03E+03	6.19E-01	1.00E+04
26	1.74E-05	1.00E+04	6.07E-01	1.00E+04
27	1.92E-06	1.00E+04	4.23E-02	1.00E+04
28	7.62E-07	1.00E+04	2.46E-02	1.00E+04
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	3.81E-05	8.72E+03	1.35E+00	1.00E+04
32	3.81E-05	8.72E+03	1.35E+00	1.00E+04
33	9.71E-04	1.95E+03	2.43E+01	3.20E+03

Table 10-7. Sr-90 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	4.35E-19	5.63E+02	3.40E-16	6.58E+02
2	NA	NA	NA	NA
3	NA	NA	NA	NA
4	NA	NA	NA	NA
5	NA	NA	NA	NA
6	NA	NA	NA	NA
7	NA	NA	NA	NA
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA
11	NA	NA	NA	NA
12	NA	NA	NA	NA
13	NA	NA	NA	NA
14	NA	NA	NA	NA
15	NA	NA	NA	NA
16	NA	NA	NA	NA
17	NA	NA	NA	NA
18	NA	NA	NA	NA
19	NA	NA	NA	NA
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	NA	NA	NA	NA
24	NA	NA	NA	NA
25	NA	NA	NA	NA
26	4.11E-13	3.26E+02	3.52E-09	3.41E+02
27	NA	NA	NA	NA
28	NA	NA	NA	NA
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	NA	NA	NA	NA
32	NA	NA	NA	NA
33	NA	NA	NA	NA

Table 10-8. Tc-99 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	5.61E-20	1.00E+04	2.02E-15	1.00E+04
2	NA	NA	NA	NA
3	NA	NA	NA	NA
4	NA	NA	NA	NA
5	NA	NA	NA	NA
6	NA	NA	NA	NA
7	NA	NA	NA	NA
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA
11	NA	NA	NA	NA
12	NA	NA	NA	NA
13	NA	NA	NA	NA
14	NA	NA	NA	NA
15	NA	NA	NA	NA
16	NA	NA	NA	NA
17	NA	NA	NA	NA
18	NA	NA	NA	NA
19	NA	NA	NA	NA
20	5.61E-20	1.00E+04	2.02E-15	1.00E+04
21	1.10E-06	1.00E+04	3.98E-02	1.00E+04
22	3.13E-05	9.50E+03	1.13E+00	9.52E+03
23	3.28E-07	1.00E+04	1.18E-02	1.00E+04
24	5.82E-17	1.00E+04	2.09E-12	1.00E+04
25	4.11E-12	1.00E+04	1.47E-07	1.00E+04
26	5.43E-15	1.00E+04	1.95E-10	1.00E+04
27	2.80E-17	1.00E+04	9.68E-13	1.00E+04
28	1.76E-10	1.00E+04	6.10E-06	1.00E+04
29 Ox	1.10E-06	1.00E+04	3.98E-02	1.00E+04
29 Red	5.61E-20	1.00E+04	2.02E-15	1.00E+04
30	4.28E-04	6.11E+03	1.54E+01	6.11E+03
31	9.45E-09	3.06E+02	3.39E-04	3.21E+02
32	7.77E-06	1.00E+04	2.80E-01	1.00E+04
33 Ox	7.77E-06	1.00E+04	2.80E-01	1.00E+04
33 Red	1.18E-02	6.00E+01	4.26E+02	6.80E+01

Table 10-9. I-129 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	1.29E-07	1.00E+04	4.62E-03	1.00E+04
2	1.11E-08	1.00E+04	3.96E-04	1.00E+04
3	4.10E-06	1.00E+04	1.46E-01	1.00E+04
4	8.49E-09	1.00E+04	3.04E-04	1.00E+04
5	1.25E-07	1.00E+04	4.50E-03	1.00E+04
6	8.20E-09	1.00E+04	2.94E-04	1.00E+04
7	1.27E-07	1.00E+04	4.56E-03	1.00E+04
8	1.75E-08	1.00E+04	6.28E-04	1.00E+04
9	5.61E-06	1.00E+04	2.00E-01	1.00E+04
10	1.73E-08	1.00E+04	6.21E-04	1.00E+04
11	5.87E-06	1.00E+04	2.10E-01	1.00E+04
12	1.46E-04	7.90E+03	5.28E+00	7.92E+03
13	3.20E-06	1.00E+04	1.14E-01	1.00E+04
14	9.28E-08	1.00E+04	3.31E-03	1.00E+04
15	1.60E-06	1.00E+04	5.76E-02	1.00E+04
16	1.02E-07	1.00E+04	3.63E-03	1.00E+04
17	1.66E-07	1.00E+04	5.94E-03	1.00E+04
18	3.17E-06	1.00E+04	1.14E-01	1.00E+04
19	3.24E-05	9.80E+03	1.17E+00	9.80E+03
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	5.88E-04	3.86E+03	2.12E+01	3.89E+03
24	1.43E-05	1.00E+04	5.13E-01	1.00E+04
25	2.45E-04	6.95E+03	8.84E+00	6.98E+03
26	1.59E-05	1.00E+04	5.74E-01	1.00E+04
27	1.62E-05	1.00E+04	5.80E-01	1.00E+04
28	2.45E-06	1.00E+04	8.83E-02	1.00E+04
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	4.89E-06	3.14E+02	1.66E-01	3.49E+02
32	4.89E-06	3.14E+02	1.66E-01	3.49E+02
33	6.60E-03	1.21E+02	2.37E+02	1.47E+02

Table 10-10. Cs-137 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	1.42E-41	1.47E+03	3.90E-44	1.67E+03
2	NA	NA	NA	NA
3	NA	NA	NA	NA
4	NA	NA	NA	NA
5	NA	NA	NA	NA
6	NA	NA	NA	NA
7	NA	NA	NA	NA
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA
11	NA	NA	NA	NA
12	NA	NA	NA	NA
13	NA	NA	NA	NA
14	NA	NA	NA	NA
15	NA	NA	NA	NA
16	NA	NA	NA	NA
17	NA	NA	NA	NA
18	NA	NA	NA	NA
19	NA	NA	NA	NA
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	NA	NA	NA	NA
24	NA	NA	NA	NA
25	NA	NA	NA	NA
26	5.26E-23	7.79E+02	2.00E-21	9.21E+02
27	NA	NA	NA	NA
28	NA	NA	NA	NA
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	NA	NA	NA	NA
32	NA	NA	NA	NA
33	NA	NA	NA	NA

Table 10-11. U-238 and progeny (i.e., Th-234 and U-234) predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1 U-238	4.64E-26	1.00E+04	5.86E-25	1.00E+04
1 Th-234	1.71E-37	1.00E+04	1.46E-25	1.00E+04
1 U-234	5.47E-31	1.00E+04	2.34E-25	1.00E+04
2 - 25	NA	NA	NA	NA
26 U-238	1.86E-18	1.00E+04	9.22E-15	1.00E+04
26 Th-234	6.89E-30	1.00E+04	2.31E-15	1.00E+04
26 U-234	7.21E-24	1.00E+04	5.77E-16	1.00E+04
27 - 28	NA	NA	NA	NA
29 Ox U-238	4.64E-26	1.00E+04	5.86E-25	1.00E+04
29 Ox Th-234	1.71E-37	1.00E+04	1.46E-25	1.00E+04
29 Ox U-234	5.47E-31	1.00E+04	2.34E-25	1.00E+04
29 Red U-238	4.76E-28	1.00E+04	6.00E-27	1.00E+04
29 Red Th-234	1.76E-39	1.00E+04	1.50E-27	1.00E+04
29 Red U-234	5.60E-33	1.00E+04	2.40E-27	1.00E+04
30 U-238	9.25E-18	1.00E+04	1.09E-18	1.00E+04
30 Th-234	3.42E-29	1.00E+04	2.72E-19	1.00E+04
30 U-234	6.62E-22	1.00E+04	4.24E-18	1.00E+04
31	NA	NA	NA	NA
32	NA	NA	NA	NA
33 Ox U-238	9.21E-19	1.00E+04	6.78E-19	1.00E+04
33 Ox Th-234	3.40E-30	1.00E+04	1.70E-19	1.00E+04
33 Ox U-234	5.90E-21	1.00E+04	1.02E-16	1.00E+04
33 Red U-238	1.21E-20	1.00E+04	8.56E-21	1.00E+04
33 Red Th-234	4.45E-32	1.00E+04	2.14E-21	1.00E+04
33 Red U-234	8.13E-23	1.00E+04	1.34E-18	1.00E+04

Table 10-12. Np-237 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	7.25E-24	1.00E+04	2.28E-19	1.00E+04
2	NA	NA	NA	NA
3	NA	NA	NA	NA
4	NA	NA	NA	NA
5	NA	NA	NA	NA
6	NA	NA	NA	NA
7	NA	NA	NA	NA
8	NA	NA	NA	NA
9	NA	NA	NA	NA
10	NA	NA	NA	NA
11	NA	NA	NA	NA
12	NA	NA	NA	NA
13	NA	NA	NA	NA
14	NA	NA	NA	NA
15	NA	NA	NA	NA
16	NA	NA	NA	NA
17	NA	NA	NA	NA
18	NA	NA	NA	NA
19	NA	NA	NA	NA
20	NA	NA	NA	NA
21	NA	NA	NA	NA
22	NA	NA	NA	NA
23	5.63E-10	1.00E+04	1.79E-05	1.00E+04
24	1.37E-20	1.00E+04	4.21E-16	1.00E+04
25	1.09E-15	1.00E+04	3.32E-11	1.00E+04
26	1.63E-18	1.00E+04	5.79E-14	1.00E+04
27	6.32E-22	1.00E+04	1.89E-17	1.00E+04
28	1.08E-12	1.00E+04	3.56E-08	1.00E+04
29	NA	NA	NA	NA
30	NA	NA	NA	NA
31	1.56E-09	6.40E+02	4.56E-05	8.44E+02
32	1.56E-09	6.40E+02	4.56E-05	8.44E+02
33	6.70E-08	1.00E+04	2.28E-03	1.00E+04

Table 10-13. Pu-238, Pu(V)-238 and progeny (i.e., U-234) predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1 Pu-238	5.60E-42	2.61E+03	1.18E-42	3.15E+03
1 Pu(V)-238	2.07E-45	2.60E+03	4.40E-46	3.15E+03
1 U-234	4.12E-26	1.00E+04	1.77E-28	1.00E+04
2 - 25	NA	NA	NA	NA
26 Pu-238	4.03E-29	1.13E+03	2.21E-26	1.43E+03
26 Pu(V)-238	1.29E-32	1.13E+03	7.70E-30	1.43E+03
26 U-234	1.78E-18	1.00E+04	3.11E-18	1.00E+04
27 - 33	NA	NA	NA	NA

Table 10-14. Pu-239, Pu(V)-239 and progeny (i.e., U-235) predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1 Pu-239	7.75E-27	1.00E+04	5.12E-24	1.00E+04
1 Pu(V)-239	2.81E-30	1.00E+04	1.88E-27	1.00E+04
1 U-235	1.83E-27	1.00E+04	4.56E-30	1.00E+04
2 - 25	NA	NA	NA	NA
26 Pu-239	6.44E-20	1.00E+04	5.36E-16	1.00E+04
26 Pu(V)-239	2.03E-23	1.00E+04	1.84E-19	1.00E+04
26 U-235	1.85E-19	1.00E+04	2.65E-20	1.00E+04
27 - 33	NA	NA	NA	NA

Table 10-15. All-Pathways Doses from the Sensitivity Scenarios

	All Pathways Dose, mrem/year											
Scenario	**H-3**	**C-14**	**Se-79**	**Sr-90**	**Tc-99**	**I-129**	**Cs-137**	**U-238**	**Np-237**	**Pu-238**	**Pu-239**	**Total[1]**
1	2.2E-09	8.2E-18	4.6E-02	9.0E-13	1.6E-13	2.6E-03	1.4E-37	6.3E-26	1.5E-18	4.6E-38	2.1E-21	4.8E-02
2	7.1E-11	2.6E-19	2.0E-02			2.2E-04						2.0E-02
3	4.4E-11	1.7E-16	1.8E-01			8.2E-02						2.7E-01
4	2.1E-09	2.4E-19	3.1E-02			1.7E-04						3.1E-02
5	2.1E-09	2.7E-14	4.9E-02			2.5E-03						5.1E-02
6	2.1E-09	2.4E-19	3.1E-02			1.7E-04						3.2E-02
7	2.1E-09	3.4E-14	4.8E-02			2.6E-03						5.1E-02
8	2.1E-09	1.5E-18	3.7E-02			3.5E-04						3.7E-02
9	2.1E-09	2.9E-16	1.2E-01			1.1E-01						2.3E-01
10	2.1E-09	1.4E-18	3.7E-02			3.5E-04						3.8E-02
11	2.1E-09	3.2E-16	1.2E-01			1.2E-01						2.4E-01
12	4.3E-11	1.7E-11	9.9E-01			3.0E+00						4.0E+00
13	2.1E-09	1.4E-16	1.1E-01			6.4E-02						1.8E-01
14	2.1E-09	6.3E-18	3.3E-02			1.9E-03						3.5E-02
15	4.6E-06	4.6E-15	1.4E-01			3.2E-02						1.7E-01
16	4.3E-10	6.5E-18	3.7E-02			2.0E-03						3.9E-02
17	3.5E-09	1.0E-17	6.0E-02			3.3E-03						6.4E-02
18	1.6E-05	2.4E-14	6.1E-01			6.4E-02						6.7E-01
19	2.2E-09	3.2E+01	2.9E+00			6.6E-01						3.6E+01
20					1.6E-13							1.6E-13
21					3.2E+00							3.2E+00
22					9.0E+01							9.0E+01
23	2.2E-09	4.3E-05	2.7E+00		9.4E-01	1.2E+01			1.2E-04			1.6E+01
24	7.0E-09	1.1E-14	7.8E-01		1.7E-10	2.9E-01			2.8E-15			1.1E+00
25	7.0E-09	9.0E-10	1.5E+00		1.2E-05	5.0E+00			2.2E-10			6.5E+00
26	2.2E-09	1.3E-12	1.5E+00	9.3E-06	1.6E-08	3.2E-01	7.1E-15	9.9E-16	3.9E-13	8.6E-22	2.2E-13	1.8E+00
27	2.2E-09	1.7E-15	1.1E-01		7.7E-11	3.3E-01			1.3E-16			4.3E-01
28	2.1E-09	9.7E-07	6.1E-02		4.9E-04	5.0E-02			2.4E-07			1.1E-01
29 Ox					3.2E+00			6.3E-26				3.2E+00
29 Red					1.6E-13			6.4E-28				1.6E-13
30					1.2E+03			1.2E-19				1.2E+03
31	3.1E-05	3.2E-03	3.4E+00		2.7E-02	9.4E-02			3.1E-04			3.5E+00
32	3.1E-05	3.2E-03	3.4E+00		2.2E+01	9.4E-02			3.1E-04			2.6E+01
33 Ox	8.7E+01	5.2E-02	6.1E+01		3.4E+04	1.3E+02		7.3E-20	1.5E-02			3.4E+04
33 Red	8.7E+01	5.2E-02	6.1E+01		3.1E+01	1.3E+02		9.2E-22	1.5E-02			3.1E+02

1. Dose calculations assume all radionuclide peak concentrations occur simultaneously which is conservative. See Tables 10-4 thru 10-14 for actual peak concentration times.

Table 10-16 Normalized Sensitivity Results for the Sensitivity Scenarios

Scenario	Variable	Base Case Value	Sensitivity Case Value	Variable Change	Dose (mrem/yr)	ΔDose/ΔVariable	Normalized Sensitivity (S_n)
1	Base Case				4.8E-02		
2	Infiltration, cm/yr	1.4E+01	7.0E+00	-7.0E+00	2.0E-02	4.0E-03	1.2E+00
3	Infiltration, cm/yr	1.4E+01	2.1E+01	7.0E+00	2.7E-01	3.2E-02	9.3E+00
4	Vault Degradation Rate, cm/s-yr	1.0E-13	9.9E-15	-9.0E-14	3.1E-02	1.9E+11	3.9E-01
5	Vault Degradation Rate, cm/s-yr	1.0E-13	1.0E-12	9.0E-13	5.1E-02	3.3E+09	6.9E-03
6	Vault Conductivity, cm/s	1.0E-12	1.0E-13	-9.0E-13	3.2E-02	1.8E+10	3.7E-01
7	Vault Conductivity, cm/s	1.0E-12	1.0E-11	9.0E-12	5.1E-02	3.3E+08	6.9E-03
8	Saltstone Degradation Rate, cm/s-yr	9.9E-14	9.0E-15	-9.0E-14	3.7E-02	1.2E+11	2.5E-01
9	Saltstone Degradation Rate, cm/s-yr	9.9E-14	1.0E-12	9.0E-13	2.3E-01	2.0E+11	4.2E-01
10	Saltstone Conductivity, cm/s	1.0E-11	1.0E-12	-9.0E-12	3.8E-02	1.1E+09	2.3E-01
11	Saltstone Conductivity, cm/s	1.0E-11	1.0E-10	9.0E-11	2.4E-01	2.1E+09	4.4E-01
12	Cases 3+5+9, cm/yr	1.4E+01		7.0E+00	4.0E+00	5.6E-01	1.6E+02
13	Relative Permeability				1.8E-01		
14	Vault Diffusivity, cm^2/s	1.0E-08	1.0E-09	-9.0E-09	3.5E-02	1.4E+06	3.0E-01
15	Vault Diffusivity, cm^2/s	1.0E-08	1.0E-07	9.0E-08	1.7E-01	1.4E+06	2.8E-01
16	Saltstone Diffusivity, cm^2/s	5.0E-09	5.0E-10	-4.5E-09	3.9E-02	2.0E+06	2.1E-01
17	Saltstone Diffusivity, cm^2/s	5.0E-09	5.0E-08	4.5E-08	6.4E-02	3.6E+05	3.7E-02
18	Cases 15 + 17, cm^2/s	1.5E-08		1.4E-07	6.8E-01	4.7E+06	1.5E+00
19	All Kds 0				3.6E+01		
20	Tc Kd = 1000, mL/g	1.0E+03			1.6E-13		
21	Tc Kd = 1, mL/g	1.0E+03	1.0E+00	-1.0E+03	3.2E+00	-3.2E-03	-6.7E+01
22	Tc Kd = 0, mL/g	1.0E+03	0.0E+00	-1.0E+03	9.0E+01	-9.0E-02	-1.9E+03
23	Vault and Saltstone degrade to 1E-6, cm/s-yr	2.0E-13	2.0E-10	2.0E-10	1.6E+01	8.0E+10	3.3E-01
24	Infiltration +25%, cm/yr	1.4E+01	1.8E+01	3.5E+00	1.1E+00	3.0E-01	8.8E+01
25	Cases 5+9+24	1.4E+01		3.5E+00	6.6E+00	1.9E+00	5.5E+02
26	Kds -10x				1.8E+00		
27	Cases 9+11	1.0E-11		9.1E-11	4.3E-01	4.2E+09	8.8E-01
28	Saltstone K0 = 1E-8, cm/s	1.0E-11	1.0E-08	1.0E-08	1.1E-01	6.2E+06	1.3E-03
29 Ox	Tc Kd = 1, U Kd = 2000, mL/g	3.0E+03	2.0E+03	-1.0E+03	3.2E+00	-3.2E-03	-2.0E+02
29 Red	Tc Kd = 1000, U Kd = 5000, mL/g	3.0E+03	6.0E+03	3.0E+03	1.6E-13	-1.6E-05	-1.0E+00
30	Cases 25 + 29 Ox	3.0E+03		-1.0E+03	1.2E+03	-1.2E+00	-7.6E+04
31	Saturated Cracks				3.5E+00		
32	Saturated Cracks + Ox				2.6E+01		

Scenario	Variable	Base Case Value	Sensitivity Case Value	Variable Change	Dose (mrem/yr)	ΔDose/ΔVariable	Normalized Sensitivity (S_n)
33 Ox	Cases 24+18+29+silted drains+ vault and Saltstone	1.0E+03		-1.0E+03	3.4E+04	-3.4E+01	-7.1E+05
33 Red	Ksat=5E-7 cm/s	1.0E+03		3.0E+03	3.1E+02	1.0E-01	2.1E+03

Attachment 1

Saltstone Disposal Facility Closure Cap Degradation for the Base Case (Institutional Control to Pine Forest Scenario) with a 25 Percent Increase in Annual Precipitation

Introduction

Infiltration through the Saltstone Disposal Facility (SDF) closure cap over 10,000 years has been estimated consistent with the methodology outlined in Phifer and Nelson 2003 for the condition where the average annual precipitation is 25 percent greater than the current historic average.

Precipitation Data Base

In the publication, "The Potential Consequences of Climate Variability and Change Overview Southeast" produced by the U.S. Global Change Research Program ((www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewsoutheast.htm)), results from the two principal models used to assess climate change in the southeast, due to CO_2 induced global warming, are discussed. It is stated that both the models (i.e., the Canadian model and the Hadley model) "provide plausible scenarios for both temperature and precipitation over the 21st century in the southeast." The Canadian model shows the area around the Savannah River Site (SRS) experiencing significantly warmer conditions, a ten percent decrease in precipitation, and resulting drier soil conditions. The Hadley model shows the area around SRS experiencing slightly warmer conditions, no more than a twenty-five percent increase in precipitation, and resulting wetter soil conditions. Based upon the plausibility of both scenarios, the U.S. Global Change Research Program states the following:

> "The Southeast is the only region for which current climate models simulate large and opposing changes in precipitation patterns over the next 100 years. The range of differences is so great that it is difficult to state with any degree of confidence that precipitation will increase or decrease in the Southeast over the next 30-100 years as atmospheric CO_2 increases."

Within NUREG-1573 the Performance Assessment Working Group (PAWG) states the following within Section 3.1 of the Executive Summary:

> "The PAWG emphasizes that there should be a limit on the range of possible site conditions, processes, and events to be considered in an LLW performance assessment and that unnecessary speculation in the assessment should be eliminated."

Specifically in reference to climate change the PAWG makes the following two statements within Section 3.2.1.2 of the text:

> "… Consideration given to the issue of evaluating site conditions that may arise from changes in climate or the influence of human behavior should be limited so as to avoid unnecessary speculation."

> "For disposal sites where the impacts of global climate change consist primarily of changes from present-day meteorologic patterns, ascertaining the nature, timing, and magnitude of related meteorological processes and events (i.e., regional consequences) and their effects on disposal site performance is highly uncertain."

As acknowledged by the U.S. Global Change Research Program, the impacts of global warming upon the Southeast are highly uncertain and assumptions regarding potential changes in precipitation in the Southeast are highly speculative. Therefore as outlined within NUREG-1573 historic and current weather data should be utilized for the determination of the base case infiltration "without the need for speculating on how climate might change." At this point the modeled changes in precipitation produced from the Canadian and Hadley models can provide bounds for conducting sensitivity analyses, but are not appropriate for use within the base case.

Based upon this information, a sensitivity analysis has been performed, which estimated the infiltration through the Saltstone Disposal Facility (SDF) closure cap over 10,000 years has been estimated for the sensitivity condition where the average annual precipitation is 25 percent greater than the current historic average as documented with Phifer and Nelson 2003. The current historic average annual precipitation from Phifer and Nelson 2003 (Table 3.0-1) is 48.77 inches/year. A 25 percent increase would result in an average annual precipitation of 60.96 inches/year. Synthetic daily precipitation over 100 years for use in the Hydrologic Evaluation of Landfill Performance (HELP) modeling was generated based upon the HELP data for Augusta, Georgia, modified with Savannah River Site (SRS) historic monthly precipitation data from the SRS 200-F Weather Station (i.e., the same weather station utilized by Phifer and Nelson 2003). Monthly precipitation data from the SRS 200-F Weather Station for the year, with an annual precipitation greater than but closest to 60.96 inches/year, was used to generate the synthetic daily precipitation data. Table 1 provides the data for 1971 from the 200-F Weather Station utilized to generate the synthetic daily precipitation data. This resulted in a 100-year synthetic daily precipitation database with the statistics outlined in Table 2.

Table 1. 1971 Precipitation Data from the 200-F Weather Station

Month	Precipitation (inches)
January	4.47
February	3.97
March	8.70
April	2.85
May	2.03
June	6.73
July	11.52
August	9.40
September	2.33
October	4.91
November	1.75
December	3.03
Total	61.69

Table 2. 100-Year Synthetic Daily Precipitation Database Statistics

	Average	Median	Standard Deviation	Minimum	High
Daily Precipitation (inches)	0.17	0.00	0.54	0.00	11.93
Yearly Precipitation (inches)	62.20	61.60	10.99	36.49	94.67

Infiltration through Intact SDF Closure Cap

The intact SDF closure cap configuration taken from Phifer and Nelson 2003 is shown in Figure 1 and Table 3. This configuration forms the basis from which degraded material properties are subsequently determined based upon a 25 percent increase in annual precipitation. Appendix A provides the HELP model input data utilized to determine the intact infiltration. The Appendix A input data deviates from that utilized within Phifer and Nelson 2003 as follows:

- The landfill area was increased to 2.58 acres, which represents a 250-foot by 450-foot area over half the vaults length.
- The slope length of the surface of the landfill was increased to 450 feet consistent with Phifer 2003.
- The vegetation was assumed to be best represented by an excellent stand of grass (i.e., input parameter “5”) due to the increased assumed precipitation.
- The slope length of the upper drainage layer was increased to 450 feet consistent with Phifer 2003.

- The slope length of the lower drainage layer was decreased to 100.75 feet consistent with Cook et al. 2005 and the Figure 1 configuration.

Additionally, the following weather input files were modified from that utilized by Phifer and Nelson 2003:

- The 100-year synthetic daily precipitation database for a 25 percent increase in annual precipitation as described above was utilized.
- Due to the increased precipitation, the evapotranspiration data file was modified to increase the evapotranspiration zone depth to 33 inches and increase the leaf area index (LAI) to 4.5. An evapotranspiration zone depth of 33 inches is between the fair (22 inches) and excellent (40 inches) values for Augusta Georgia. A LAI of 4.5 is the maximum for Augusta, Georgia.

These modifications from Phifer and Nelson 2003 were continued through the degraded cases.

The average annual infiltration through the upper geosynthetic clay liner (GCL) was determined to be 0.64746 inches/year.

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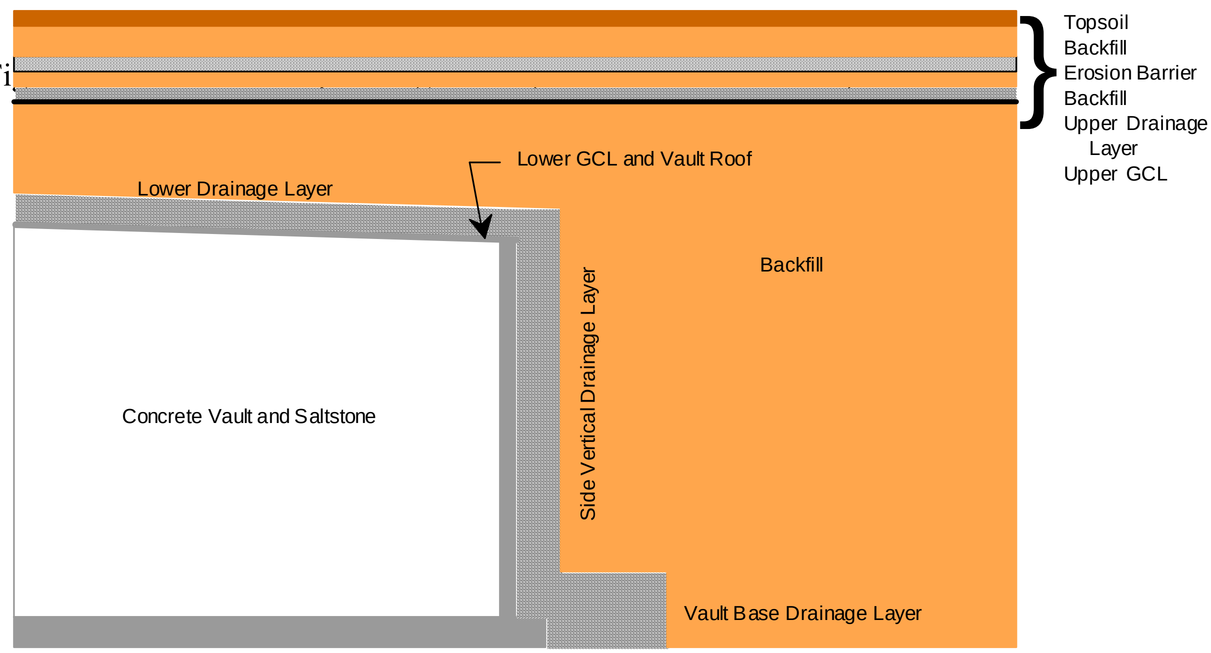


Table 3. Intact SDF Closure Cap Configuration and HELP Model Required Soil Property Data (Phifer and Nelson 2003)

Layer	Thickness (inches)	Saturated Hydraulic Conductivity (cm/sec)	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)
Topsoil	6	1.00E-03	0.40	0.11	0.058
Upper Backfill	30	1.00E-04	0.37	0.24	0.136
Erosion Barrier	12	3.97E-04	0.06	0.056	0.052
Middle Backfill	12	1.00E-04	0.37	0.24	0.136
Geotextile Filter Fabric	-	-	-	-	-
Upper Drainage Layer	12	1.00E-01	0.38	0.08	0.013
Upper GCL	0.2	5.00E-09	0.75	0.747	0.400
Lower Backfill	58.65	1.00E-04	0.37	0.24	0.136
Geotextile * Filter Fabric	-	-	-	-	-
Lower Drainage Layer	24	1.00E-01	0.38	0.08	0.013
Lower GCL	0.2	5.00E-09	0.75	0.747	0.400

* It is assumed that a geotextile filter fabric will be placed above the drainage layers to minimize the infiltration of fines from the overlying layers into the drainage layers. However it is not necessary to include the filter fabric in the HELP models.

Erosion and Topsoil and Upper Backfill Layer Thickness

The topsoil and upper backfill layers, which are located above the erosion barrier, are subject to erosion. For the institutional control to pine forest land use scenario, it is assumed that the closure cap will be vegetated with bamboo during the institutional control period, with a combination of bamboo and pine trees for 200 years immediately following the institutional control period, and with a pine forest thereafter. The projected erosion rate for both the topsoil and upper backfill layers has been determined utilizing the Universal Soil Loss Equation (Horton and Wilhite 1978; Goldman et al. 1986). The Universal Soil Loss Equation (USLE) is expressed as:

$A = R \times K \times LS \times C \times P$ where:

A = soil loss (tons/acre/year)

R = rainfall erosion index (100 ft·ton/acre per in/hr)

K = soil erodibility factor, tons/acre per unit of R

LS = slope length and steepness factor, dimensionless

C = vegetative cover factor, dimensionless

P = erosion control practice factor, dimensionless

Table 4 presents the USLE parameter values which were utilized in Phifer 2003 in order to determine the erosion rate for the topsoil and upper backfill layers. The rainfall erosion index, R, of 260 in Table 4 is based upon historic rainfall data. Since it is assumed that average annual precipitation is 25 percent greater than the current historic average, the R value should also increase. According to Goldman et al. 1986, the R value can “be approximated with reasonable accuracy by using 2-year, 6-hr rainfall data.” The increased R value has been estimated by selecting an R value for a nearby South Carolina coastal plain location, which has a historic 2-year, 6-hr rainfall 25 percent greater than that of SRS. According to the NOAA Atlas 14, Volume 2, Version 2 Ohio River Basin and Surrounding States for North Carolina and South Carolina (ftp://hdsc.nws.noaa.gov/pub/hdsc/data/orb/na14orbv2_nc2y6h.pdf), the historic 2-year, 6-hr rainfall for SRS is 2.7 inches. A 25 percent increase would result in a 2-year, 6-hr rainfall of 3.4 inches. The area around Georgetown, South Carolina, has a 2-year, 6-hr rainfall of 3.4 inches. From Figure 5.2 of Goldman et al. 1986, the Georgetown area has an R value of slightly greater than 350. Therefore an R value of 360 will be utilized rather than a value of 260.

Table 4. USLE Parameter Values

USLE Parameter	Value Utilized	Source
R for SRS location	260	Horton and Wilhite 1978
K for topsoil	0.28	Phifer and Nelson 2003 and Goldman et al. 1986 Figure 5.6
K for backfill	0.20	Phifer and Nelson 2003 and Goldman et al. 1986 Figure 5.6
LS for 450-foot 3% slope	0.45	Goldman et al. 1986 Table 5.5
C for both bamboo and pine forest	0.001	Horton and Wilhite 1978
P for no supporting practices	1	Not applicable

Based upon the Universal Soil Loss Equation, Table 4 parameter values except using an R value of 360, the following soil losses were estimated:

Topsoil with a natural successional forest has an estimated soil loss of 0.0454 tons/acre/year ($A = 360 \times 0.28 \times 0.45 \times 0.001 \times 1$). Based upon the dry bulk density, the estimated soil loss can be converted to a loss in terms of depth of loss per year. From Jones and Phifer (2002), the dry bulk density of topsoil was taken as 90 lbs/ft^3. Topsoil with a natural successional forest has an estimated depth of soil loss of approximately 2.8E-04 inches/year.

($Loss = \dfrac{0.0454\ tons/acre/year \times 2000\ lbs/ton \times 12\ inches/foot}{43{,}560\ ft^2/acre \times 90\ lbs/ft^3}$).

Backfill with a natural successional forest has an estimated soil loss of 0.0324 tons/acre/year ($A = 360 \times 0.20 \times 0.45 \times 0.001 \times 1$). Based upon the dry bulk density, the estimated soil loss can be converted to a loss in terms of depth of loss per year. From Jones and Phifer (2002), the dry bulk density of backfill was taken as 104 lbs/ft^3. Backfill with a natural successional forest has an estimated depth of soil loss of approximately 1.7E-04 inches/year.

($Loss = \dfrac{0.0324\ tons/acre/year \times 2000\ lbs/ton \times 12\ inches/\ foot}{43{,}560\ \ ft^2\ /acre \times 104\ lbs/\ ft^3}$).

Table 5 provides the resulting topsoil thickness with time.

Table 5. Calculation of Topsoil Thickness with Time

Year	Thickness
0	6” – (0 years × 2.8E-04 inches/year) = 6”
100	6” – (100 years × 2.8E-04 inches/year) = 5.972”
300	6” – (300 years × 2.8E-04 inches/year) = 5.916”
550	6” – (550 years × 2.8E-04 inches/year) = 5.846”
1,000	6” – (1,000 years × 2.8E-04 inches/year) = 5.72”
1,800	6” – (1,800 years × 2.8E-04 inches/year) = 5.496”
3,400	6” – (3,400 years × 2.8E-04 inches/year) = 5.048”
5,600	6” – (5,600 years × 2.8E-04 inches/year) = 4.432”
10,000	6” – (10,000 years × 2.8E-04 inches/year) = 3.2”

Since the topsoil does not completely erode away within the 10,000 years of interest, no reduction in the upper backfill layer occurs.

Erosion Barrier Hydraulic Properties

As outlined in Phifer and Nelson 2003 (Table 5.4-1), degradation of the erosion barrier’s hydraulic properties occurs due to pine forest succession and associated root penetration. The extent of degradation at any given time is based upon the thickness of soil materials overlying the erosion barrier. Phifer 2003 conservatively assumed a constant 4-inch thick topsoil layer in calculating the hydraulic properties of the erosion barrier. This same assumption can be conservatively made for the current calculations for time periods 0 through 5,600 years (see Table 5). Therefore the erosion barrier hydraulic properties over time from 0 to 5,600 years previously calculated by Phifer 2003 (see Table 6) can be utilized for the current infiltration estimates. However, the hydraulic properties at 10,000 years must be calculated since the topsoil is estimated to have eroded to below 4 inches.

Table 6. Erosion Barrier Hydraulic Properties with Time

Year	K_v	Porosity (N)	Field Capacity (FC)	Wilting Point (WP)
0	3.97E-04 cm/s	0.06	0.056	0.052
100	3.97E-04 cm/s	0.06	0.056	0.052
300	3.98 E-04 cm/s	0.06	0.562	0.521
550	3.99E-04 cm/s	0.061	0.0566	0.0523
1,000	4.01E-04 cm/s	0.062	0.0574	0.0526
1,800	4.06E-04 cm/s	0.065	0.0587	0.0532
3,400	4.15E-04 cm/s	0.069	0.0614	0.0545
5,600	4.27E-04 cm/s	0.075	0.0651	0.0562
10,000	4.51E-04 cm/s	0.088	0.0726	0.0596

Area of holes in erosion barrier at 10,000 years due to root penetration:

Average Erosion Barrier Depth = 3.2” + 30” + ½(12”) = 39.2” ≈ 3.27’

Root Diameter for 4-6’ roots at 3.27’:

3” diameter at 1’ depth and 0.25” at 6’

$(3''-0.25'')/(6'-1') = 0.55''/\ ft$

Diameter = 0.25” + [(6’ – 3.27’) × 0.55”/ft] = 1.75”

Area of for 4-6’ roots at 3.3’:

Area = $4 \times \frac{1}{4}\pi D^2 = \pi D^2 = \pi(1.75'')^2 = 9.6\ in^2$

Root Diameter for 1-12’ root at 3.27’:

3” diameter at 1’ depth and 0.25” at 12’

$(3''-0.25'')/(12'-1') = 0.25''/\ ft$

Diameter = 0.25” + [(12’ – 3.27’) × 0.25”/ft] = 2.43”

Area of for 1-12’ roots at 3.3’:

Area = $\frac{1}{4}\pi D^2 = \frac{1}{4}\pi(2.43'')^2 = 4.6\ in^2$

Total area of holes in erosion barrier per tree:

Total area = $9.6\ in^2 + 4.6\ in^2 = 14.2\ in^2 \times ft^2/144\ in^2 \approx 0.1\ ft^2$/tree

Total area of holes per acre per 100 years:

400 trees/acre/100 years

Total area = 0.1 ft^2/tree × 400 trees/acre/100 years = 40 ft^2/ acre/100 years

This is the same area of holes as used for topsoil eroded to 4 inches thick; therefore the erosion barrier hydraulic properties at year 10,000 previously calculated by Phifer 2003 (see Table 6) is still applicable.

Upper GCL Holes

As outlined in Phifer and Nelson 2003 (Table 5.4-1), degradation of the geosynthetic clay liner (GCL) occurs due to pine forest succession and associated root penetration. The extent of degradation at any given time is based upon the thickness of soil materials overlying the GCL. Phifer 2003 conservatively assumed a constant 4-inch thick topsoil layer in determining the number of holes in the GCL. This same assumption can be conservatively made for the current calculations for time periods 0 through 5,600 years (see Table 7). Therefore the number of holes in the GCL over time from years 0 to 5,600 previously calculated by Phifer 2003 (see Table 7) can be utilized for the current infiltration estimates. However, the number of holes in the GCL at 10,000 years must be calculated since the topsoil is estimated to have eroded to below 4 inches.

Table 7. Number of Holes in the GCL with Time

Year	# of installation defects in upper GCL / acre due to root penetration
0	0
100	0
300	7,432
550	26,013
1,000	59,458
1,800	118,916
3,400	237,832
5,600	401,341
10,000	764,406 (see calculation below)

Area of holes in upper GCL due to root penetration:

Upper GCL Depth = 3.2” + 30” + 12” + 12” + 12” = 69.2” ≈ 5.76’

Root Diameter for 4-6’ roots at 5.76’:

3” diameter at 1’ depth and 0.25” at 6’

$(3''-0.25'')/(6'-1') = 0.55''/\,ft$

Diameter = 0.25” + [(6’ – 5.76’) × 0.55”/ft] = 0.38”

Area of for 4-6’ roots at 5.8’:

Area = 4 × $\frac{1}{4}\pi D^2 = \pi D^2 = \pi(0.38'')^2 = 0.45\ in^2$

Root Diameter for 1-12’ root at 5.76’:

3” diameter at 1’ depth and 0.25” at 12’

$(3''-0.25'')/(12'-1') = 0.25''/\,ft$

Diameter = 0.25” + [(12’ – 5.76’) × 0.25”/ft] = 1.81”

Area of for 1-12’ roots at 3.3’:

Area = $\frac{1}{4}\pi D^2 = \frac{1}{4}\pi(1.81'')^2 = 2.57\ in^2$

Total area of holes in erosion barrier per tree:

Total area = $0.45 \text{ in}^2 + 2.57 \text{ in}^2 = 3.02 \text{ in}^2 \times \text{ft}^2/144 \text{ in}^2 \approx 0.021 \text{ ft}^2$/tree

Total area of holes per acre per 100 years:

400 trees/acre/100 years

Total area = 0.021 ft^2/tree × 400 trees/acre/100 years = 8.4 ft^2/ acre/100 years

Year	Area of holes in upper GCL / acre due to root penetration
10,000	8 ft^2/ acre [1] + [(10,000 yrs – 300 yrs) × 8.4 ft^2/ acre/100 years = 822.8 ft^2/ acre

[1] 200 years after the end of institutional control (i.e. at year 300) it is assumed that the entire cap is covered with pine (i.e. 400 mature trees per acre) that has resulted in 8 ft^2/ acre of holes in the GCL (Phifer 2003, page F-6)

Number of one-square-centimeter holes in upper GCL per acre due to root penetration (each HELP model installation defect for a flexible membrane liner (FML) is assumed to be one square centimeter):

$1 \text{ cm}^2 = 0.001076391 \text{ ft}^2$ so 0.001076391 ft^2/installation defect

Year	Percent of GCL area degraded due to root penetration
10,000	(822.8 ft^2/ acre ÷ $43{,}560 \text{ ft}^2$/ acre) × 100 = 1.89

Year	# of installation defects in upper GCL / acre due to root penetration
10,000	822.8 ft^2/ acre ÷ 0.001076391 ft^2/installation defect = 764,406

Middle Backfill Layer and Upper Drainage Layer Hydraulic Properties

The following assumptions have been taken from Phifer and Nelson 2003 Appendix P, and Phifer 2003 Appendix F:

- It is assumed that colloidal clay migration from the 1-foot-thick middle backfill to the underlying 1-foot-thick upper drainage layer causes the middle backfill saturated hydraulic conductivity to increase over time and that of the upper drainage layer to decrease over time.
- The mass of clay to fill the upper drainage layer void volume (0.38) is 11,836.3 g.
- The available clay mass in the middle backfill layer is 9,434.7 g/ft^3.
- There is not enough clay in the middle backfill layer to fill the upper drainage layer. Therefore it will be assumed that half the clay content of the middle backfill migrates into the upper drainage layer, at which point the two layers essentially become the same material and material property changes cease. Based upon this, it will be assumed that the endpoint saturated hydraulic conductivity of the layers will become that of the log mid-point between the initial backfill and upper drainage layer conditions. It will also be assumed that the endpoint porosity, field capacity, and wilting point will become the arithmetic average of the backfill and upper drainage

layer. This results in the Table 8 initial and end state hydraulic properties for the middle backfill layer and upper drainage layer:

Table 8. Middle Backfill Layer and Upper Drainage Layer Initial and End State Hydraulic Properties

Hydraulic Parameter	Initial Middle Backfill	Initial Upper Drainage Layer	End State
K	1.0E-04 cm/s	1.0E-01 cm/s	3.2E-03 cm/s
N	0.37	0.38	0.375
FC	0.24	0.08	0.16
WP	0.136	0.013	0.0745

- It will be assumed that the clay migrates out of the middle backfill into the upper drainage layer with the water flux containing 63 mg/L of colloidal clay. It will also be assumed (Phifer and Nelson 2003) that the time to achieve the endpoint conditions will be based upon the estimated water flux into the upper drainage layer and migration of half the clay content of the middle backfill layer (i.e., 9,434.7 g/ft^3 ÷ 2 = 4,717.4 g/ft^3).

Determine flux of water into the upper drainage layer:

The intact SDF closure cap modeling with a 25% increase in average annual precipitation results in the following average annual flux of water into the upper drainage layer:

Precipitation = 62.14 inches/year

Runoff = 1.312 inches/year

Evapotranspiration = 38.249 inches/year

Flux of water into upper drainage layer = Precipitation – (Runoff + Evapotranspiration)

Flux of water into upper drainage layer = 62.14 in/yr – (1.312 in/yr + 38.249 in/yr)

Flux of water into upper drainage layer = 22.579 in/yr

The above flux is based upon the best case cap conditions; therefore, will determine the flux based upon the Preliminary 10,000 year conditions as follows:

- 10,000 year eroded topsoil at 3.2 inches (see above)
- 10,000 year erosion barrier conditions with K = 4.51E-04 cm/s; n = 0.088; FC = 0.0726; WP = 0.0596 (see above)
- Middle backfill and upper drainage layer at end state conditions with K = 3.2E-03 cm/s; n = 0.375; FC = 0.16; WP = 0.0745 (see above)
- Upper GCL with 764,406 holes/acre (see above)
- Lower drainage layer with intact backfill properties (used since 10,000 year conditions for this layer not yet determined)

The preliminary 10,000 year SDF closure cap modeling with a 25% increase in average annual precipitation results in the following average annual flux of water into the upper drainage layer:

Precipitation = 62.14 inches/year

Runoff = 1.639 inches/year

Evapotranspiration = 38.307 inches/year

Flux of water into upper drainage layer = Precipitation – (Runoff + Evapotranspiration)

Flux of water into upper drainage layer = 62.14 in/yr – (1.639 in/yr + 38.307 in/yr)

Flux of water into upper drainage layer = 22.194 in/yr

There is very little difference between the flux into the upper drainage layer with either the intact or 10,000-year conditions. Therefore, a water flux into the upper drainage layer of ~22.6 in/yr will be used for determination of the time when the endpoint properties are reached. Determine yearly clay migration into the upper drainage layer:

Flux into upper drainage layer = 22.6 in/yr

Colloidal clay concentration = 63 mg/L

Flux through a 1 ft^2 area = 22.6 in/yr × ft/12 in × 1 ft^2 = 1.88 ft^3/yr

Clay flux = 1.88 ft^3/yr × 63 mg/L × 2.831685E-02 m^3/ ft^3 × 1000L/ m^3 = 3,354 mg/yr = 3.35 g/yr

Determine time it takes for the 4,717.4 g of clay to migrate from the middle backfill layer to the upper drainage layer:

Time = 4,717.4 g ÷ 3.35 g/yr = 1,408 years

Determine middle backfill and upper drainage layer hydraulic property variation with time:

It will be assumed (Phifer and Nelson 2003) that the K of the middle backfill layer is increasing log linearly with time from 1.0E-04 cm/s to 3.2E-03 cm/s, until year 1,408 at which time the K becomes static. Conversely, the K of the upper drainage layer is decreasing log linearly with time from 1.0E-01 cm/s to 3.2E-03 cm/s, until year 1,408 at which time the K becomes static. Porosity (n), FC, and WP behaves similarly but in an arithmetic linear manner.

Determine fraction change for each year:

Year	Fraction
0	0 ÷ 1,408 = 0
100	100 ÷ 1,408 = 0.0710
300	300 ÷ 1,408 = 0.213
550	550 ÷ 1,408 = 0.391
1,000	1,000 ÷ 1,408 = 0.710
1,800	1.0
3,400	1.0
5,600	1.0
10,000	1.0

Table 9 provides the variation in K, n, FC, and WP with time in the middle backfill.

Table 9. Middle Backfill K, n, FC, and WP with Time

Year	Fraction, F	K [1] (cm/s)	n [2]	FC [3]	WP [4]
0	0	0.0001	0.37	0.24	0.136
100	0.0710	0.00013	0.37	0.234	0.132
300	0.213	0.00021	0.371	0.223	0.123
550	0.391	0.00039	0.372	0.209	0.112
1,000	0.710	0.0012	0.374	0.183	0.0923
1,800	1.0	0.0032	0.375	0.16	0.0745
3,400	1.0	0.0032	0.375	0.16	0.0745
5,600	1.0	0.0032	0.375	0.16	0.0745
10,000	1.0	0.0032	0.375	0.16	0.0745

[1] $K = 10^{[-4 + ((-2.5 - (-4))F)]} = 10^{(-4 + 1.5F)}$

[2] n = 0.37 + (0.375 – 0.37)F

[3] FC = 0.24 – (0.24 – 0.16)F

[4] WP = 0.136 – (0.136 – 0.0745)F

Table 10 provides the variation in K, n, FC, and WP with time in the upper drainage layer.

Table 10. Upper Drainage Layer K, n, FC, and WP with Time

Year	Fraction, F	K [1] (cm/s)	n [2]	FC [3]	WP [4]
0	0	0.1	0.38	0.08	0.013
100	0.0710	0.078	0.38	0.086	0.017
300	0.213	0.048	0.379	0.097	0.026
550	0.391	0.026	0.378	0.11	0.037
1,000	0.710	0.0086	0.376	0.14	0.057
1,800	1.0	0.0032	0.375	0.16	0.0745
3,400	1.0	0.0032	0.375	0.16	0.0745
5,600	1.0	0.0032	0.375	0.16	0.0745
10,000	1.0	0.0032	0.375	0.16	0.0745

[1] $K = 10^{[-1 + ((-2.5 - (-1))F)]} = 10^{(-1 - 1.5F)}$

[2] $n = 0.38 - (0.38 - 0.375)F$

[3] $FC = 0.08 + (0.16 - 0.08)F$

[4] $WP = 0.013 + (0.0745 - 0.013)F$

Lower Drainage Layer Hydraulic Properties

It is assumed (Phifer and Nelson 2003) that colloidal clay migration from the overlying backfill is driven by the water flux through the upper GCL. This water flux driven clay migration enters into the 2-foot thick lower drainage layer and fills the lower drainage layer from the bottom up. This reduces the saturated hydraulic conductivity of the clay filled portion from 1.0E-01 to 1.0E-04 cm/s (i.e. the saturated hydraulic conductivity of the overlying backfill layer). As the thickness of the lower drainage layer filled with clay increases the overall hydraulic conductivity of the layer decreases. This is different from that assumed for the upper drainage layer since the lower drainage layer has significantly more backfill overlying it. The HELP model was run for each year with all of the previously degraded properties (see above) without degradation of the lower drainage layer in order to determine the infiltration through the upper GCL. Table 11 provides the results.

Table 11. Infiltration through Upper GCL without Degradation of Lower Drainage Layer

Year	Infiltration through upper GCL (inches/year)
0	0.64746
100	0.85024
300	6.77425
550	15.66587
1,000	21.11318
1,800	21.87119
3,400	22.02097
5,600	22.04617
10,000	22.11663

It is assumed (Phifer and Nelson 2003) that there is a linear increase in the infiltration over time between data points.

Determine cumulative volume of water through the lower drainage layer over time:

Year	Infiltration through upper GCL (inches/year)	Time Step Volume [1] (inches)	Cumulative Volume [2] (inches)	Cumulative Volume over one ft^2 area [3] (ft^3)
0	0.64746	0	0	0
100	0.85024	74.885	74.885	6.2
300	6.77425	762.449	837.334	69.8
550	15.66587	2,805.015	3,642.349	303.5
1,000	21.11318	8,275.286	11,917.635	993.1
1,800	21.87119	17,193.748	29,111.383	2,425.9
3,400	22.02097	35,113.728	64,225.111	5,352.1
5,600	22.04617	48,473.854	112,698.965	9,391.6
10,000	22.11663	97,158.160	209,857.125	17,488.1

[1] $V = [I_1 \times (T_2 - T_1)] + [1/2 \times (I_2 - I_1)(T_2 - T_1)]$, where I = infiltration at time step 1 or 2;

T = time at time step 1 or 2

[2] Cumulative Volume = Previous cumulative volume + Volume at current time step

[3] Cumulative Volume over one ft^2 area = (Cumulative Volume ÷ 12 in/ft) × 1 ft^2

The following assumptions have been taken from Phifer and Nelson 2003 Appendix P and Phifer 2003 Appendix F:

- The mass of clay to required fill the lower drainage layer void volume (0.38) is 23,672.9 g
- The total flux of water into the lower drainage layer required to completely fill it with clay is 13,269.8 ft^3

Determine the mass of clay that has migrated into the lower drainage layer at the end of each time step:

Year	Mass of clay into lower drainage layer
0	0
100	6.2 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 11.1 g
300	69.8 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 124.5 g
550	303.5 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 541.4 g
1,000	993.1 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 1,771.6 g
1,800	2,425.9 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 4,327.7 g
3,400	5,352.1 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 9,547.9 g
5,600	9,391.6 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 16,754.2 g
10,000	17,488.1 ft^3 × 63 mg/L × 28.31685 L/ ft^3 × g/1000 mg = 31,198.1 g

Determine the fraction of the lower drainage layer filled at the end of each time step:

Year	Fraction of the lower drainage layer filled
0	0
100	11.1 g ÷ 23,672.9 g = 0.000469
300	124.5 g ÷ 23,672.9 g = 0.00526
550	541.4 g ÷ 23,672.9 g = 0.0229
1,000	1,771.6 g ÷ 23,672.9 g = 0.0748
1,800	4,327.7 g ÷ 23,672.9 g = 0.183
3,400	9,547.9 g ÷ 23,672.9 g = 0.403
5,600	16,754.2 g ÷ 23,672.9 g = 0.708
10,000	31,198.1 g ÷ 23,672.9 g = 1.318 (the fraction can not be greater than 1.0; this indicates that the lower drainage layer is completely silted in prior to year 10,000)

Table 12 provides the hydraulic properties of the clean and clay filled portion of the lower drainage layer.

Table 12. Lower Drainage Layer Clean and Clay Filled Hydraulic Properties

Material	Saturated Hydraulic Conductivity (cm/s)	Porosity	Field Capacity	Wilting Point
Clean	1.0E-01	0.38	0.08	0.013
Clay filled	1.0E-04	0.22 [1]	0.21 [1]	0.20 [1]

[1] Taken from Phifer and Nelson 2003 and Phifer 2003

Determine the equivalent horizontal hydraulic conductivity of the lower drainage layer over time:

The equivalent horizontal hydraulic conductivity for horizontal flow in a series of horizontal layers with different saturated hydraulic conductivities can be determined from the following equation (Freeze and Cherry 1979):

$K_h = \sum_{i=1}^{n} \frac{K_i \, d_i}{d}$, where K_h = equivalent horizontal saturated hydraulic conductivity, K_i = horizontal saturated hydraulic conductivity of i^{th} layer, d_i = thickness of i^{th} layer, d = total thickness

The fraction, F, equals d_i/d for the clay filled portion and d_i/d for the clean drainage layer material equals (1 – F), making the equation:

$$K_h = \left(K_{filled} \times F\right) + \left[K_{clean} \times \left(1 - F\right)\right]$$

Year	Equivalent K (cm/s)
0	0.1
100	(0.0001 × 0.000469) + [0.1 × (1 - 0.000469)] = 0.1
300	(0.0001 × 0.00526) + [0.1 × (1 - 0.00526)] = 0.0995
550	(0.0001 × 0.0229) + [0.1 × (1 - 0.0229)] = 0.0977
1,000	(0.0001 × 0.0748) + [0.1 × (1 - 0.0748)] = 0.0925
1,800	(0.0001 × 0.183) + [0.1 × (1 - 0.183)] = 0.0817
3,400	(0.0001 × 0.403) + [0.1 × (1 - 0.403)] = 0.0597
5,600	(0.0001 × 0.708) + [0.1 × (1 - 0.708)] = 0.0293
10,000	(0.0001 × 1.0) + [0.1 × (1 – 1.0)] = 0.0001

Determine the equivalent n, FC, and WP for the lower drainage layer over time:
In an analogous manner to that for K, the equivalent n, FC, and WP can be determined based upon the fraction filled as follows:

$$n = \left(n_{filled} \times F\right) + \left[n_{clean} \times (1 - F)\right]$$

$$FC = \left(FC_{filled} \times F\right) + \left[FC_{clean} \times (1 - F)\right]$$

$$WP = \left(WP_{filled} \times F\right) + \left[WP_{clean} \times (1 - F)\right]$$

Year	Equivalent n
0	(0.22 × 0) + [0.38 × (1 - 0)] = 0.38
100	(0.22 × 0.000469) + [0.38 × (1 - 0.000469)] = 0.38
300	(0.22 × 0.00526) + [0.38 × (1 - 0.00526)] = 0.379
550	(0.22 × 0.0229) + [0.38 × (1 - 0.0229)] = 0.376
1,000	(0.22 × 0.0748) + [0.38 × (1 - 0.0748)] = 0.368
1,800	(0.22 × 0.183) + [0.38 × (1 - 0.183)] = 0.351
3,400	(0.22 × 0.403) + [0.38 × (1 - 0.403)] = 0.316
5,600	(0.22 × 0.708) + [0.38 × (1 - 0.708)] = 0.267
10,000	(0.22 × 1.0) + [0.38 × (1 – 1.0)] = 0.22

Year	Equivalent FC
0	(0.21 × 0) + [0.08 × (1 - 0)] = 0.08
100	(0.21 × 0.000469) + [0.08 × (1 - 0.000469)] = 0.08
300	(0.21 × 0.00526) + [0.08 × (1 - 0.00526)] = 0.081
550	(0.21 × 0.0229) + [0.08 × (1 - 0.0229)] = 0.083
1,000	(0.21 × 0.0748) + [0.08 × (1 - 0.0748)] = 0.090
1,800	(0.21 × 0.183) + [0.08 × (1 - 0.183)] = 0.104
3,400	(0.21 × 0.403) + [0.08 × (1 - 0.403)] = 0.132
5,600	(0.21 × 0.708) + [0.08 × (1 - 0.708)] = 0.172
10,000	(0.21 × 1.0) + [0.08 × (1 – 1.0)] = 0.21

Year	Equivalent WP
0	$(0.20 \times 0) + [0.013 \times (1 - 0)] = 0.013$
100	$(0.20 \times 0.000469) + [0.013 \times (1 - 0.000469)] = 0.0131$
300	$(0.20 \times 0.00526) + [0.013 \times (1 - 0.00526)] = 0.0140$
550	$(0.20 \times 0.0229) + [0.013 \times (1 - 0.0229)] = 0.0173$
1,000	$(0.20 \times 0.0748) + [0.013 \times (1 - 0.0748)] = 0.0270$
1,800	$(0.20 \times 0.183) + [0.013 \times (1 - 0.183)] = 0.0472$
3,400	$(0.20 \times 0.403) + [0.013 \times (1 - 0.403)] = 0.0884$
5,600	$(0.20 \times 0.708) + [0.013 \times (1 - 0.708)] = 0.145$
10,000	$(0.20 \times 1.0) + [0.013 \times (1 – 1.0)] = 0.20$

Table 13 provides a summary of the lower drainage layer hydraulic properties with time.

Table 13. Summary Lower Drainage Layer Hydraulic Properties with Time

Year	K (cm/s)	n	FC	WP
0	0.1	0.38	0.08	0.013
100	0.1	0.38	0.08	0.0131
300	0.0995	0.379	0.081	0.0140
550	0.0977	0.376	0.083	0.0173
1,000	0.0925	0.368	0.090	0.0270
1,800	0.0817	0.351	0.104	0.0472
3,400	0.0597	0.316	0.132	0.0884
5,600	0.0293	0.267	0.172	0.145
10,000	0.0001	0.22	0.21	0.20

The HELP model was rerun for each time step with all of the degraded properties (see above) including that of the lower drainage layer. Infiltration through the upper GCL did not change with the addition of the degraded lower drainage layer properties. Therefore the above estimated lower drainage layer hydraulic properties over time are valid.

Year that Lower Drainage Layer Completely Silts In

From previous calculations above, the following were determined:

It takes a total of 13,269.8 ft^3 of infiltrating water to completely silt in the lower drainage layer.

The lower drainage layer completely silts in between year 5,600 and year 10,000.

Through year 5,600, the infiltrating water volume was 9,391.6 ft^3.

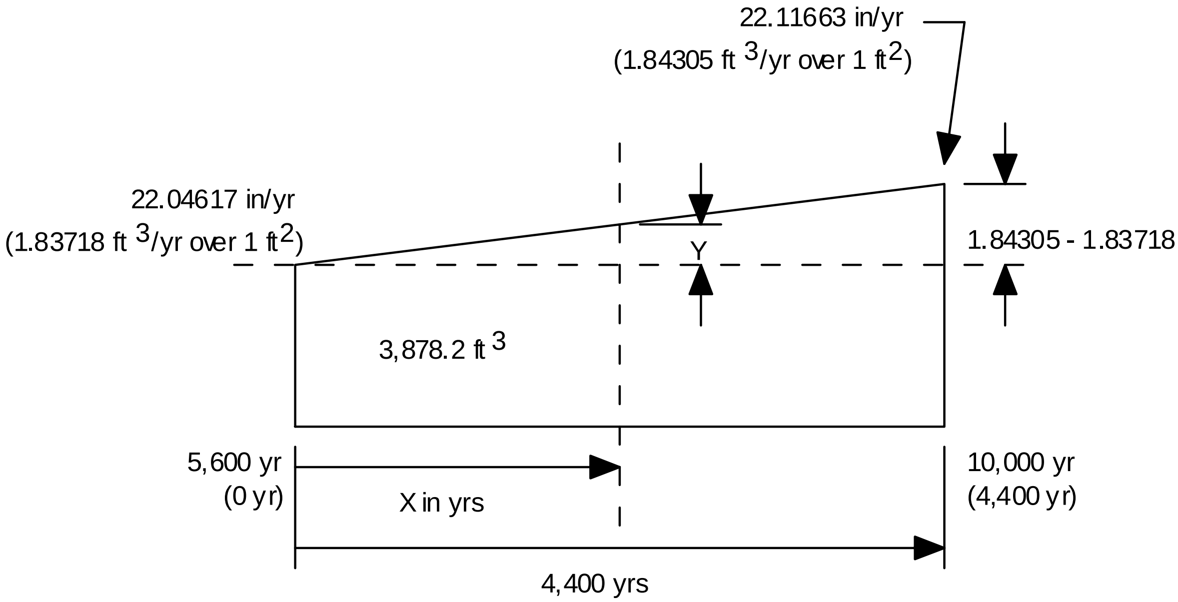
At year 5,600, the infiltration through the upper GCL was 22.04617 inches/year (1.83718 ft^3/yr over 1 ft^2), and, at year 10,000, it was 22.11663 inches/year (1.84305 ft^3/yr over 1 ft^2).

It is assumed that infiltration varies linearly between year 5,600 and year 10,000.

Determine water volume remaining after year 5,600 to completely silt in the lower drainage layer:

$V = 13{,}269.8\ ft^3 - 9{,}391.6\ ft^3 = 3{,}878.2\ ft^3$

Determine time to completely silt in the lower drainage layer as defined by year 5,600 plus X (years). The following calculation determines the formula to use to interpolate at what year the water volume is reached that will completely silt in the lower drainage layer (3,878.2 ft^3):



$$\frac{Y}{X} = \frac{(1.84305 - 1.83718)}{4{,}400}$$

$$Y = \frac{X}{4{,}400}(1.84305 - 1.83718)$$

$$1.83718\ ft^3/yr\ X - \frac{1}{2}\ X\left[\frac{X}{4{,}400\ yr}\left(1.84305\ ft^3/yr - 1.83718\ ft^3/yr\right)\right] = 3{,}878.2\ ft^3$$

$$1.83718\ ft^3/yr\ X + 6.67E-7\ ft^3/yr^2\ X^2 = 3{,}878.2\ ft^3$$

Determine X (years):

X (years)	3,878.2 (lower drainage layer silt in water volume)
2,000	3,677.0
2,100	3,861.0
2,109	3,877.8 (Statistically equal to 3,878.2 ft^3)

Year lower drainage layer completely silts in:

Year = 5,600 + 2,109 = 7,709

At year 7,709 the lower drainage layer completely silts in and has the following properties: saturated hydraulic conductivity = 1.0E-04 cm/s; porosity = 0.22; field capacity = 0.21; wilting point = 0.20.

Vault Base Drainage Layer Hydraulic Properties

It is assumed that colloidal clay migration from the overlying backfill is driven by the water flux through the upper GCL. This water-flux-driven clay migration enters into the 5-foot-thick vault base drainage layer and fills the lower drainage layer from the bottom up. The saturated hydraulic conductivity of the clay filled portion is reduced from 1.0E-01 to 1.0E-04 cm/s (i.e., the saturated hydraulic conductivity of the overlying backfill layer), while the conductivity of the clean portion remains at 1.0E-01 cm/s. The thickness of the clay filled portion increases with time while the thickness of the clean portion decreases with time. This is essentially the same process as described above for the lower drainage layer.

The infiltration through the upper GCL and the cumulative water flux into the vault base drainage layer remains the same as that calculated for the lower drainage layer above.

Determine mass of clay to fill the vault base drainage layer void volume (0.38):

Assume clay bulk density is 1.1 g/cm^3

Look at a 1-ft^2 area of the 5-foot thick the vault base drainage layer (i.e. 2 ft^3)

Void volume = 0.38 × 5 ft^3 = 1.9 ft^3

Clay mass per ft^3 = 1.1 g/cm^3 × 1.9 ft^3 × 2.831685E-02 m^3/ft^3 × 1,000,000 cm^3/m^3 = 59,182.2 g

The mass of clay that has migrated into the vault base drainage layer remains the same as that calculated for the lower drainage layer above.

Determine the fraction of the vault base drainage layer filled at the end of each time step:

Year	Fraction, F, of the vault base drainage layer filled
0	0
100	11.1 g ÷ 59,182.2 g = 0.000188
300	124.5 g ÷ 59,182.2 g = 0.00210
550	541.4 g ÷ 59,182.2 g = 0.00915
1,000	1,771.6 g ÷ 59,182.2 g = 0.0299
1,800	4,327.7 g ÷ 59,182.2 g = 0.0731
3,400	9,547.9 g ÷ 59,182.2 g = 0.161
5,600	16,754.2 g ÷ 59,182.2 g = 0.283
10,000	31,198.1 g ÷ 59,182.2 g = 0.527

Table 14 provides the thicknesses of the 0.1 and 0.0001 cm/s portions of the vault base drainage layer with time.

Table 14. Vault Base Drainage Layer Thicknesses

Year	Fraction, F, of the vault base drainage layer filled	0.1 cm/s layer thickness (ft) [1]	0.0001 cm/s layer thickness (ft) [2]
0	0	5	0
100	0.000188	4.9991	0.0009
300	0.00210	4.99	0.01
550	0.00915	4.954	0.046
1,000	0.0299	4.85	0.15
1,800	0.0731	4.64	0.36
3,400	0.161	4.20	0.80
5,600	0.283	3.58	1.42
10,000	0.527	2.36	2.64

[1] Thickness = 5’ – (5’ × F)

[2] Thickness = 5’ × F

Degradation of the side vertical drainage layer does not occur until the vault base drainage layer has completely degraded. Since the vault base drainage layer does not completely degrade during the first 10,000 years, the side vertical drainage layer does not degrade during this time frame.

Summary PORFLOW Input

Table 15 provides pertinent parameters values over time for input to PORFLOW modeling based upon the above calculations.

Table 15. Vault 4 PORFLOW Input for a 25 Percent Increase in Annual Precipitation

Year	Infiltration through Upper GCL (in/yr)	Lower Drainage Layer K_s (cm/s)	Side Vertical Drainage Layer K_s [1] (cm/s)	Thickness of Upper Portion of the Vault Base Drainage Layer with a K_s of 0.1 cm/s (feet)	Thickness of Lower Portion of the Vault Base Drainage Layer with a K_s of 0.0001 cm/s (feet)
0	0.64746	0.1	1.00E-01	5	0
100	0.85024	0.1	1.00E-01	4.9991	0.0009
300	6.77425	0.0995	1.00E-01	4.99	0.01
550	15.66587	0.0977	1.00E-01	4.954	0.046
1,000	21.11318	0.0925	1.00E-01	4.85	0.15
1,800	21.87119	0.0817	1.00E-01	4.64	0.36
3,400	22.02097	0.0597	1.00E-01	4.20	0.80
5,600	22.04617	0.0293	1.00E-01	3.58	1.42
7,709 [2]	ND	0.0001	1.00E-01	ND	ND
10,000	22.11663	0.0001	1.00E-01	2.36	2.64

GCL = geosynthetic clay liner

K_s = saturated hydraulic conductivity

ND = not determined

[1] Assumes no degradation of the side vertical drainage layer occurs until the vault base drainage layer has been filled with colloidal clay.

[2] This is the year that the lower drainage layer is assumed to completely silt in and the saturated hydraulic conductivity is assumed to remain at 1.00E-04 cm/s thereafter.

Appendix A, Intact SDF Closure Cap with Max Precip - 0 Years

HELP Model Input Data File (input file name: ZMAXI.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	3 (barrier soil liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	6		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.06	0.056	0.052	0.056
4	1	12		0.37	0.24	0.136	0.24
5	2	12		0.38	0.08	0.013	0.08
6	3	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.38	0.08	0.013	0.08
9	3	0.2		0.75	0.747	0.40	0.75

Appendix A Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	3.97E-04					
4	1	1.00E-04					
5	2	1.00E-01	450	3			
6	3	5.00E-09					
7	1	1.00E-04					
8	2	1.00E-01	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	3				
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix B, Preliminary Degraded SDF Closure Cap with Max Precip – 10,000 Years

HELP Model Input Data File (input file name: ZMAXP10K.D10)

Preliminary 10,000 Year Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 in
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 48.0	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	3.2		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.088	0.0726	0.0596	0.0726
4	1	12		0.375	0.16	0.0745	0.16
5	2	12		0.375	0.16	0.0745	0.16
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.37	0.24	0.136	0.24
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix B Preliminary 10,000 Year Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	4.51E-04					
4	1	3.20E-03					
5	2	3.20E-03	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	1.00E-04	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	764,406	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data is missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix C, Degraded SDF Closure Cap with Max Precip - 100 Years

HELP Model Input Data File (input file name: ZMAXD1.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	3 (barrier soil liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	5.972		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.06	0.056	0.052	0.056
4	1	12		0.37	0.234	0.132	0.234
5	2	12		0.38	0.086	0.017	0.086
6	3	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.38	0.08	0.0131	0.08
9	3	0.2		0.75	0.747	0.40	0.75

Appendix C Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	3.97E-04					
4	1	1.30E-04					
5	2	7.80E-02	450	3			
6	3	5.00E-09					
7	1	1.00E-04					
8	2	1.00E-01	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	3				
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix D, Degraded SDF Closure Cap with Max Precip - 300 Years

HELP Model Input Data File (input file name: ZMAXD2.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	5.916		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.06	0.0562	0.0521	0.0562
4	1	12		0.371	0.223	0.123	0.223
5	2	12		0.379	0.097	0.026	0.097
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.379	0.081	0.0140	0.081
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix D Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	3.98E-04					
4	1	2.10E-04					
5	2	4.80E-02	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	9.95E-02	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	7432	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix E, Degraded SDF Closure Cap with Max Precip - 550 Years

HELP Model Input Data File (input file name: ZMAXD3.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	5.846		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.061	0.0566	0.0523	0.0566
4	1	12		0.372	0.209	0.112	0.209
5	2	12		0.378	0.11	0.037	0.11
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.376	0.083	0.0173	0.083
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix E Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	3.99E-04					
4	1	3.90E-04					
5	2	2.60E-02	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	9.77E-02	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	26013	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix F, Degraded SDF Closure Cap with Max Precip – 1,000 Years

HELP Model Input Data File (input file name: ZMAXD4.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	5.72		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.062	0.0574	0.0526	0.0574
4	1	12		0.374	0.183	0.0923	0.183
5	2	12		0.376	0.14	0.057	0.14
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.368	0.090	0.027	0.090
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix F Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	4.01E-04					
4	1	1.20E-03					
5	2	8.60E-03	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	9.25E-02	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	59458	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix G, Degraded SDF Closure Cap with Max Precip – 1,800 Years

HELP Model Input Data File (input file name: ZMAXD5.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	5.496		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.065	0.0587	0.0532	0.0587
4	1	12		0.375	0.16	0.0745	0.16
5	2	12		0.375	0.16	0.0745	0.16
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.351	0.104	0.0472	0.104
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix G Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	4.06E-04					
4	1	3.20E-03					
5	2	3.20E-03	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	8.17E-02	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	118916	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix H, Degraded SDF Closure Cap with Max Precip – 3,400 Years

HELP Model Input Data File (input file name: ZMAXD6.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	5.048		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.069	0.0614	0.0545	0.0614
4	1	12		0.375	0.16	0.0745	0.16
5	2	12		0.375	0.16	0.0745	0.16
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.316	0.132	0.0884	0.132
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix H Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	4.15E-04					
4	1	3.20E-03					
5	2	3.20E-03	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	5.97E-02	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	237832	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix I, Degraded SDF Closure Cap with Max Precip – 5,600 Years

HELP Model Input Data File (input file name: ZMAXD7.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	4.432		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.075	0.0651	0.0562	0.0651
4	1	12		0.375	0.16	0.0745	0.16
5	2	12		0.375	0.16	0.0745	0.16
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.267	0.172	0.145	0.172
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix I Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	4.27E-04					
4	1	3.20E-03					
5	2	3.20E-03	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	2.93E-02	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	401341	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

Appendix J, Degraded SDF Closure Cap with Max Precip – 10,000 Years

HELP Model Input Data File (input file name: ZMAXD8.D10)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.58 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	450 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	5 (i.e., an excellent stand of grass)
HELP Model Computed Curve Number = 48.00	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	4 (flexible membrane liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	3.2		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	1	12		0.088	0.0726	0.0596	0.0726
4	1	12		0.375	0.16	0.0745	0.16
5	2	12		0.375	0.16	0.0745	0.16
6 *	4	0.2		0.75	0.747	0.40	0.75
7	1	58.65		0.37	0.24	0.136	0.24
8	2	24		0.22	0.21	0.20	0.21
9	3	0.2		0.75	0.747	0.40	0.75

* The input porosity, field capacity, and wilting point values of the upper GCL are ignored by the HELP model, since the upper GCL is designated as a geomembrane in order for the HELP model to take into account the holes produced by root penetration.

Appendix J Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity * (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	1	4.51E-04					
4	1	3.20E-03					
5	2	3.20E-03	450	3			
6	4	5.00E-09					
7	1	1.00E-04					
8	2	1.00E-04	100.75	2			
9	3	5.00E-09					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	1				
5	2				
6	4	0	764406	1	
7	1				
8	2				
9	3				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data are missing from the table.

* The HELP model output often produces an increased number of significant digits for the Effective Saturated Hydraulic Conductivity over that of the actual input.

References:

Phifer, M.A., and Nelson, E.A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

Phifer, M.A. 2003. Saltstone Disposal Facility Mechanical Stabilized Earth Vault Closure Cap Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00523, Westinghouse Savannah River Company, Aiken, South Carolina.

Goldman, S.J., Jackson, K., Bursztynsky, T.A. 1986. Erosion and Sediment control Handbook, McGraw-Hill Publishing Company, New York.

Horton, J. H. and Wilhite, E. L. 1978. Estimated Erosion Rate at the SRP Burial Ground, DP-1493, E. I. du Pont de Nemours and Company, Aiken, South Carolina. April 1978.

Jones, W. E. and Phifer, M. A. 2002. Corrosion and Potential Subsidence Scenarios for Buried B-25 Waste Containers, WSRC-TR-2002-00354, Westinghouse Savannah River Company, Aiken, South Carolina. September 2002.

Action Item 11 (8/17/05): *Support of Decontamination Factors*

Provide information supporting the decontamination factors assumed in the report titled "Radionuclides in SRS Salt Waste" (RAI 11).

SRS Response: Additional details supporting the basis for the assumptions used to determine radionuclide removal efficiencies used in *Radionuclides in SRS Salt Waste* (WSRC 2005) can be found in a report titled *Detailed Basis for Assumptions Used to Determine Radionuclide Process Removal Efficiencies* (Pike 2005). A copy of this report is included with this submittal.

References:

Pike, J. A., 2005, *Detailed Basis for Assumptions Used to Determine Radionuclide Process Removal Efficiencies*, CBU-PIT-2005-00215, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2005, *Radionuclides in SRS Salt Waste*, CBU-PIT-2005-00195, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.